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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

THE GRAMPIAN HIGHLANDS

by

H. H. READ, D.Sc., A.R.C.Sc., F.R.S.

(SECOND EDITION)

REVISED BY

A. G. MACGREGOR, M.C., D.Sc.

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE

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PRICE FOUR SHILLINGS NET

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FOREWORD TO REVISED EDITION

GRAMPIAN HIGHLAND PROBLEMS have been intensively studied since the publication of the first edition of this Regional Guide; the volume of research, and its wide field, may be judged from the additional references to literature. In most chapters this new work has involved only minor amendments to the text. Seven of the original sketch maps have, however, been altered, in order to bring them up to date; two diagrams concerned with Sir Edward Bailey's work have been replaced by new ones; three of the original diagrams (Figs. 3, 13 and 25 of the 1st Edition) have been withdrawn; and maps illustrating respectively the effects of the Great Glen Fault according to Professor W. Q. Kennedy, and a new account of the geology of the Machrihanish Coalfield, are reproduced by permission from recent publications.

There are major alterations in the sections of Chapter IV dealing with the Dalradian Series. Ideas on Dalradian stratigraphy and tectonics have changed so radically in the last decade that these sections have, of necessity, been largely re-written. The reviser has attempted to deduce and summarize the present stage in the evolution of Sir Edward Bailey's nappe hypothesis for the Southern Highlands. To illustrate the summary, Fig. 7 and Plate V have been newly drawn. This synthesis has been submitted to Sir Edward Bailey and accepted by him as representing his present views.

Other new matter includes a revised account of the Carboniferous (Chapter X) based on notes supplied by Dr. M. Macgregor, a brief description of Permian rocks in Islay and Kintyre (Chapter XI) based on notes supplied by Dr. J. Pringle, and a revised and documented summary of Economic Geology (Chapter XIV).

The reviser has throughout kept in touch with Professor Read, and has made certain additions on his suggestion.

An EXHIBIT illustrating the Geology and Scenery of the district described in this volume is set out on the first gallery of the Museum of Practical Geology, Exhibition Road, South Kensington, London, S.W.7.

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(*C*.1772)

MAMORE FOREST LOOKING SOUTH FROM THE SUMMIT OF BEN NEVIS

[For explanation, *see* p. viii]

THE GRAMPIAN HIGHLANDS

I. INTRODUCTION

THE BOUNDARIES OF the area described here are formed by two great dislocations, the Highland Boundary Fault and the Great Glen Fault (Fig. 1). The first of these runs from Stonehaven on the North Sea south-westwards by Dunkeld, Comrie and Aberfoyle to the foot of Loch Lomond and the Firth of Clyde. The second occupies the hollow of the Great Glen and passes from Inverness along Loch Ness, Loch Oich, Loch Lochy and Loch Linnhe into Mull. It was long thought to be continued along the east side of Colonsay and through the Loch Gruinart hollow in Islay. Recently, however, W. Q. Kennedy has brought forward strong evidence indicating that the fault passes to the north-west of Colonsay. This hypothesis has been provisionally adopted in the present publication (Fig. 3).

Movement along the great dislocations which isolate this area is still taking place, for these faults are two of the most notable earthquake lines in Britain. Strong earthquakes occurred in the Inverness district in 1816, 1888, 1890 and 1891, whilst over 400 shocks have been recorded in the neighbourhood of Comrie on the Highland Boundary Fault.

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Physical Features

The north-eastern and south-western sea-margins of the area are totally different in character (Fig. 1). On the north-east, the straight coast of the Moray Firth probably follows the strikes of the planes of unconformity at the bases of the Trias and of the Middle and Upper Old Red Sandstone of the district. On the south-west, the most remarkable feature of the coast is the long, narrow fiords that run far into the interior. These have been attributed to erosion along intersecting fractures (Gregory, 1913), but the more general view regards them as submerged land valleys overdeepened by ice-erosion during the Glacial period.

This district includes the highest ground in Britain. Ben Nevis reaches 4,406 ft., whilst a considerable area in the Cairngorms exceeds 4,000 ft. Viewed from any commanding height, the Central Highlands show a general tendency of their ridges and mountain tops to reach up to a more or less uniform level (Frontispiece). No isolated central chain overtowers the neighbouring hills. The Central Highlands have been carved by the agents of denudation from a high table-land which has at the present day a general summit-level of 2,000 to 3,000 ft. The levelling-down began before the deposition of the Old Red Sandstone and has continued to the present day.

The slope of the original high plateau of the whole Highlands was most probably towards the south-east. Before the re-excavation of the hollow of the Great Glen along the old shattered rocks and overlying deposits of that belt, great consequent rivers flowed south-eastwards towards the position of the North Sea. The development of the Great Glen hollow led to the separation of the North-west Highlands from the Grampian Highlands and to the beheading of the consequent rivers. A good example of this is seen in the south-western part of the area, where the great valleys of Glen Scaddle, Glen Gour and Glen Tarbert on the north-west side of the Great Glen are continued by Glen Nevis, the Lairigmor and River

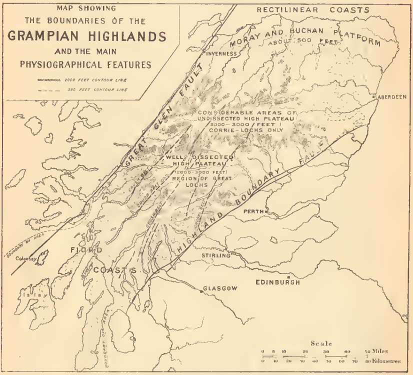

Fig. 1.—*Physiography of the Grampian Highlands.*

Leven valley, and Glen Coe on the south-east side. The Garry-Tay is the chief consequent river of the Central Highlands; the relics of others occur along the Highland Border.

As the overlying Old Red Sandstone and later rocks were denuded off the Highland plateau, the metamorphic rocks were revealed. These consist of rocks of varied resistance to erosive agents, and form belts running in a general north-north-east to south-south-west direction. Continued denudation led to the formation of longitudinal streams running in valleys carved out of the weaker members of the metamorphic rocks, or controlled by the strike-directions of these. The River Spey, an example of these longitudinal streams, seems to have cut back so as to intercept the old consequent streams of the North-west Highlands as far west as Loch Eil. Again, the development of an active longitudinal tributary of the Garry-Tay along a belt of weak strata and shattered rocks in the present Loch Tay district led to the relegation of the consequent Garry to a minor position. The continued adjustment of the river-system as the heterogeneous foundation of crystalline rocks was eroded more and more has led to departures from the simple consequent or longitudinal character of individual streams, whilst capture of portions of one river-system by another has occurred in many districts. As examples of this last process may be instanced the capture of the headwaters of the Geldie by the Feshie, and of the Upper Don by the Avon.

In addition to the factors already noted, the denudation of the Central Highlands has been markedly influenced by a group of faults, with accompanying belts of shattered and weakened rocks, which run in a general north-north-east to south-south-west, or north to south, direction (Fig. 1). Whilst these shatter-belts cross many great valleys without affecting their courses, they have been seized upon in many cases by the agents of denudation and deep hollows formed along their trends. They are particularly well developed in the South-west Highlands. Examples are: the Loch Tay Fault, which has influenced the shape of Loch Tay; the Tyndrum Fault, whose southern prolongation or branches have affected the configuration of Loch Fyne; the Loch Awe–Glen Strae–Loch Ericht Fault along the shatter-belt of which is situated, for instance, the long and narrow hollow of Loch Ericht. W. Q. Kennedy thinks these fracture-lines (1946, Fig. 4) are characterized by great shatter-belts because they are essentially wrench-faults, not dip-slip faults.

The fertile plain on the south side of the Moray Firth, and its continuation in the Buchan promontory of Aberdeenshire, are due to the removal of a series of soft Mesozoic and Old Red Sandstone strata and to the consequent reappearance of the underlying floor of metamorphic and igneous rocks.

The lochs of the Central Highlands have a remarkable distribution. Only a few, apart from the small examples in the high corries of the Cairngorms, are found north-east of a line drawn from Inverness to Perth. South-west of this line occur the grandest lochs of the Highlands. As Peach and Horne pointed out, this contrast depends fundamentally upon the difference in the character of the High Plateau in the two regions at the beginning of the Glacial period. In the first region there were extensive areas of undissected plateau, the valleys were open and comparatively shallow and led gradually up to high ground. No concentration of ice-erosion was possible. The second region, on the other hand, is a highly dissected district where deep through-valleys have been established between high mountains, and where the cols form low passes across the existing watershed. In such regions ice-reservoirs were established and, from these, vast quantities of ice passed out by somewhat restricted outlets. As an example of such a cauldron may be given the Moor of Rannoch, from which lead the outlets now containing Loch Rannoch, Loch Ericht, Loch Treig, etc. It will be seen from the foregoing, therefore, that the lochs of the South-western Highlands can be explained as due to glacial erosion. The work of the Scottish Loch Survey under Sir J. Murray and L. Pullar showed that the great lochs occupying rock-basins possessed features readily explicable by ice-erosion. Such features are : U-shape in cross-section, lack of adjustment between the large valley rock-basins and tributary streams, the presence of several distinct basins in one loch, and the occurrence of the greatest depths where the valley is most constricted and of the steepest slopes at concave bends where ice-erosion was most powerful. In some cases, the original hollow coincided with a belt of shattered rock along which erosion was exceedingly active. For instance, Loch Ericht, lying along such a shatter-belt, has a length of fourteen and half miles but a width not exceeding half a mile, whilst its greatest depth, 512 ft., occurs at the constricted part of the loch. As a typical valley rock-basin may be instanced Loch Lomond, which lies across the strike of the strata in a valley in great part excavated by one of the original consequent streams draining towards the south-east. Fine examples of corrie-lochs are found in the Cairngorms (Pl. IA).

Scenery

Two contrasted types of mountain-scenery are presented by the Central Highlands. In the Northern and Eastern Grampians—*e.g.* the Cairngorm area and Glen Clova—great relics of the high plateau remain as broad, level moorlands cut into by deep glens and scarred by gigantic corrie-cliffs. Towards the south-west this type of mountain-scenery gradually passes into a more highly dissected type of rugged pinnacles, crests and ridges. The detail of this latter form depends upon the geological character and structure of the rocks. Resistant beds, such as quartzites (Pl. IB), grits or massive gneisses, rise into lofty summits. If no marked guiding planes are present, conical forms result, as in the quartzite mountains of Schichallion, Ben-y-Gloe and Paps of Jura. A series of metamorphosed grits—the Ben Ledi Grits—makes a line of conspicuous mountains close to the Highland Boundary Fault; prominent peaks in this line are Ben Vorlich, Ben Ledi and Ben Lomond. Between these resistant quartzites, grits and gneisses, belts of weaker strata such as slates, limestones and phyllites have been excavated into valleys. The tors, scree-slopes and savage corries of the Cairngorms and Lochnagar exemplify the mode of denudation of the granites which form these mountain groups. The bold cliff scenery of Glen Coe, Ben Nevis and adjacent regions is carved out of volcanic rocks or larger granitic masses (Pl. VIIA).

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[1] Stocks of Geological Survey publications (memoirs and maps) were destroyed by enemy action ; reprinting is in hand.

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[1] Geological Survey Maps of the Grampian Highlands

On the Scale of 1 *mile to* 1 *inch:—*

Colour-printed: Sheets 19 (Bowmore); 27 (Portaskaig); 28 (Jura); 35 (Colonsay); 36 (Kilmartin); 37 (Inverary); 44 (Mull); 45 (Oban); 53 (Ben Nevis); 54 (Rannoch); 55 (Blair Athole); 64 (Kingussie); 65 (Balmoral); 67 (Stonehaven); 74 (Grantown-on-Spey); 83 (Inverness); 84 (Nairn); 86 (Huntly); 96 (Banff).

Hand-coloured: Sheets 12 (Campbeltown); 20 (Killean); 29 (Rothesay); 38 (Loch Lomond); 46 (Balquhidder); 47 (Crieff); 56 (Blairgowrie); 57 (Forfar); 66 (Banchory); 75 (Tomintoul); 76 (Inverurie); 77 (Aberdeen); 85 (Rothes); 87 (Peterhead); 94 (Cromarty); 95 (Elgin); 97 (Fraserburgh).

On the scale of 4 *miles to* 1 *inch:—*

Sheets 9 (Aberdeenshire and Banffshire); 12 (Forfar and Kincardine); 13 (Islay Archipelago); 14 (Firth of Clyde); 16 (South Kintyre).

[1] Stocks of Geological Survey publications (memoirs and maps) were destroyed by enemy action ; reprinting is in hand.

II. SUMMARY OF GEOLOGY AND TABLE OF FORMATIONS

THE GEOLOGICAL FORMATIONS making up the Grampian Highlands may be grouped into five divisions, as follows:—

A. Pre-Cambrian: Lewisian (including associated igneous rocks) and Torridonian (and Bowmore Sandstone).

B. Highland Schists, possibly pre-Cambrian: Central Highland Granulites (Moine Series) and Dalradian Series. (*For other views on age, see p.* 34.)

C. Cambro-Ordovician: Highland Border Series.

D. Upper Palaeozoic and Mesozoic: Old Red Sandstone, Carboniferous, Permian and Trias.

E. Tertiary and Recent: ? Pliocene, Pleistocene and Recent.

Of these formations by far the most important with respect to area is the Dalradian, followed by the Central Highland Granulites, and this by the Old Red Sandstone. The other formations listed are represented by small areas. Doubtful remnants of Jurassic and Cretaceous rocks are merely mentioned here.

In addition to the sedimentary rocks of these formations, the Grampian Highlands contain *igneous rocks,* both contemporaneous and intrusive, in great variety. The time-relations of many of these are questions for discussion, but certain broad tendencies of opinion are given.

Contemporaneous igneous rocks, poured out as lavas, occur in four formations of the district:—

(1) The *Dalradian* rocks of the Loch Awe area contain a great series of basic lavas.

(2) The *Highland Border Series* contains spilitic lavas.

(3) The *Lower Old Red Sandstone* of Lorne and Glen Coe is mostly represented by lavas of various types, well seen in Glen Coe. The *Middle Old Red Sandstone* has a thin volcanic zone in the Moray Firth area.

(4) *Carboniferous* basaltic lavas are found in the Campbeltown district, and on Glas Eilean in the Sound of Islay.

Intrusive igneous rocks, forced in a molten condition into older rocks, may be broadly grouped into the following age-classes:—

(1) *Older Igneous Rocks: earlier than or contemporaneous with the regional metamorphism of the Highland Schists.* This group is mainly in the Dalradian Series (Chap. V).

(2) Igneous rocks, basic and ultrabasic in character, intrusive into the *Highland Border Series,* with which they are here described.

(3) *Newer Igneous Rocks: later than the regional metamorphism of the Highland Schists, but in part earlier than the Downtonian.* This group of intrusives, mainly in the north-east Grampian area, is considered before the Old Red Sandstone (Chap. VII).

Table of Geological Formations and Rock-Groups represented in the Grampian Highlands

SUPERFICIAL DEPOSITS			
QUATERNARY	Recent and Pleistocene	Blown Sand: sandhills of Culbin, etc. Peat Freshwater Alluvium along rivers Marine Alluvia, including Raised Beach Deposits Fluvio-glacial sands and gravels, Moraines of Valley Glaciers, Morainic Drift and Boulder-clay: Glacial Deposits	

SOLID FORMATIONS AND ROCK GROUPS		CONTEMPORANEOUS IGNEOUS ROCKS	INTRUSIVE IGNEOUS ROCKS
TERTIARY . . ?Pliocene	Gravels and clays in the Buchan District of Aberdeenshire		Tertiary basalt and dolerite dykes
MESOZOIC AND UPPER PALAEOZOIC	Permian and Trias . . Sandstones of Elgin and Kintyre		Camptonite Dykes, age late Carboniferous or Permian
	Carboniferous: Millstone Grit and Coal Measures; Carboniferous Limestone Series; Calciferous Sandstone Series	Basaltic Lavas; Basaltic Lavas — at Campbeltown	Permo-Carboniferous quartz-dolerite dykes
	Old Red Sandstone: Upper Old Red Sandstone; Middle Old Red Sandstone; Lower Old Red Sandstone	Thin andesitic lavas in north-east Thick suite of andesitic and other lavas at Oban, Glen Coe, Ben Nevis	Plutonic and hypabyssal intrusions of L.O.R.S. or Caledonian Age (*e.g.* 'Newer Granites')
PERIOD OF MOUNTAIN BUILDING MOVEMENTS (CALEDONIAN OROGENY)			
LOWER PALAEOZOIC	Cambro-Ordovician:—Highland Border Series	Spilitic Lavas	Gabbros, Serpentine
PRE-CAMBRIAN	Torridonian:—Grits, flags, sandstones, phyllites and limestones; Lewisian:—Mainly gneisses of igneous origin (orthogneisses) — Only in Islay and Colonsay		Basic Dykes and Pegmatites
OF UNCERTAIN AGE: POSSIBLY PRE-CAMBRIAN	Dalradian Series; Central Highland Granulites (Moine Series) — HIGHLAND SCHISTS	Metamorphosed lava-flows and ash-beds	'Older Igneous Rocks'—serpentines, gabbros, epidiorites and amphibolites, granites and pegmatites.

(4) *Newer Igneous Rocks : mainly of Lower Old Red Sandstone Age.* Representatives of this group cut rocks of Lower Old Red Sandstone age. They are dealt with here before the Old Red Sandstone is described (Chap. VIII).

(5) *Permo-Carboniferous Dykes:* a series of east-and-west quartz-dolerite dykes some of which cut Middle Old Red Sandstone, and comparable with similar dykes of Permo-Carboniferous age occurring in the Midland Valley of Scotland. They are described after the Permian and Trias.

(6) *Camptonite Suite of South-west Highlands:* the age of this group is probably late Carboniferous or Permian; some dykes are later than (5). These rocks are considered after the Permian and Trias.

(7) *Tertiary Dykes:* a great series of north-west dykes, mostly basic, connected with the Tertiary igneous centres of Mull, Arran, etc.

In the Table on the preceding page there is given a brief synopsis of the sedimentary rocks, contemporaneous igneous rocks and intrusive igneous rocks that are found in the Grampian Highlands.

(*B*.738)

A.—Loch Coire an Lochain, Braeriach, Cairngorms
[For explanation, *see* p. viii]

(*C*.1833)

B.—On Stob Choire Claurigh, Ben Nevis
[For explanation, *see* p. viii]

III. LEWISIAN AND TORRIDONIAN OF ISLAY AND JURA

BY MOST SCOTTISH geologists the continuation of the Great Glen Fault has long been considered to pass along the east coast of Colonsay and through the Loch Gruinart hollow of Islay. The rocks making Colonsay and the Rhinns of Islay are classed with the Lewisian and Torridonian of

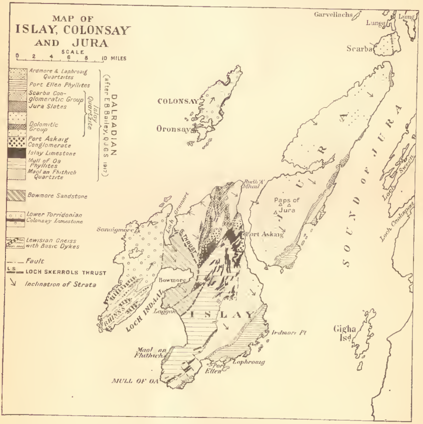

FIG. 2.—*Geological Map of Islay, Colonsay and Jura.*

the North-west Highlands. The Loch Gruinart Fault, according to Sir E. B. Bailey's hypothesis of 1917, separates the Torridonian of the Rhinns of Islay from a group known as the Bowmore Sandstones which, though usually considered as Torridonian also, have been taken by some as Moine or Dalradian.

W. Q. Kennedy (1946) has eliminated the Loch Gruinart Fault in Islay. He correlates the Loch Skerrols Thrust with a portion of the Moine Thrust which he supposes to pass south-east of Colonsay. Kennedy's line for the Great Glen Fault, which he regards as a wrench-fault, passes *north-west* of Colonsay (Fig. 2), and his Moine–Loch Skerrols Thrust meets it a few miles north-north-east of that island. On the north-west side of the fault he supposes the under-sea outcrop of the Moine Thrust to be displaced some sixty-five miles south-south-westwards (Fig. 3). E. B. Bailey does not now accept the identification of the Loch Skerrols Thrust with the Moine Thrust (p. 33).

1. Lewisian

Rocks referred on lithological grounds to the Lewisian Formation occupy an area of less than twenty square miles in the Rhinns of Islay, where they are overlaid by basement beds considered to be Torridonian. At the north end of Colonsay, a tiny area of Lewisian rocks, less than one-eighth of a square mile in size, is seen. In both islands, the marginal relations of the two formations are complicated by shearing or folding.

The Islay Lewisian rocks consist of acid and basic igneous gneisses. The original rocks were most likely biotite- and hornblende-gneisses like those found in the Lewisian Gneiss of the North-west Highlands, but they are now in the condition of microbreccias and show a cataclastic metamorphism characterized by granulation and mylonization, similar to that produced by the post-Cambrian movements in the North-west Highlands. These gneisses are cut by a series of basic intrusions, comprising epidiorite, hornblende-schist, diorite, augite-diorite, and augite-hypersthene-diorite.

The Colonsay Lewisian Gneisses are coarse-grained banded quartzo-feldspathic rocks with dark knots and streaks. The principal rock-types are amphibolites, hornblende-gneisses, biotite-gneisses and pegmatite. Like the Islay rocks, they show cataclastic shattering.

2. Torridonian (and Bowmore Sandstone)

The general consensus of opinion regards the correlation of the sedimentary rocks of Colonsay and the northern part of the Rhinns of Islay with the Torridonian as extremely probable. J. W. Gregory dissented from this view and was followed, so far as the Bowmore Sandstone is concerned, by G. Barrow and J. F. N. Green in regarding these rocks as Dalradian and pre-Torridonian.

The sedimentary rocks of the *Rhinns of Islay and Bowmore* were grouped by S. B. Wilkinson as follows:—

Applecross Division	C. *Bowmore Grits:* red, green and grey grits or arkose, in places very coarse-grained and containing pebbles of quartzite, felsite, granite, etc.—*Blackrock Pebble Bed.*
	B. *Kilchiaran Slate and Grit Series:* grey green and black slates and phyllites alternating with grey schistose grit and thin bands of sandy limestone.
Diabaig Division	A. *Rhinns Conglomerate Series:* schistose epidotic grits, thin phyllite bands, and local conglomerate.

Of these groups, A and B occur entirely to the north-west of the Loch Gruinart hollow, and C to the south-east, except for a small and doubtful area near Gortan. S. B. Wilkinson and B. N. Peach (1930), followed by W. Q. Kennedy (1946), consider that the Loch Gruinart Fault does not exist.

The eastern margin of the Bowmore group is taken by Wilkinson and Peach to be the *Loch Skerrols Thrust*, which brings on the Islay Dalradian assemblage (Fig. 2). E. B. Bailey (1917) suggested that the Loch Gruinart

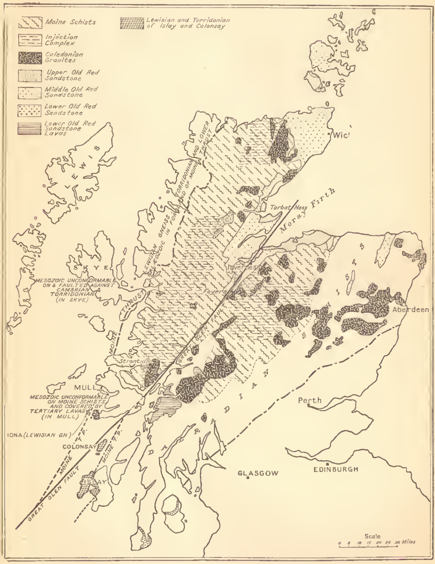

FIG. 3.—*Geological Map of the Scottish Highlands, showing Effects of the Great Glen Fault according to W. Q. Kennedy.*

(Reproduced, by kind permission, from 'The Great Glen Fault,' *Quart. Journ. Geol. Soc.*, vol. cii, pt. i, 1946, Fig. 2.)

Fault existed, that it was the continuation of the Great Glen Fault, and that the Loch Skerrols Thrust might be correlated with the Moine Thrust of the North-west Highlands (p. 33). Other workers, however, accept the

Loch Gruinart Fault but deny the existence of the Loch Skerrols Thrust. For instance, G. Barrow considered the Bowmore group to belong to the Moine Series and, in accordance with certain views summarized later on p. 16, to be at the edge of the Central Highland Quartzite of the Dalradian. J. F. N. Green likewise regards the Bowmore Sandstone as conformable to the Central Highland Quartzite. J. W. Gregory agreed with Green that the supposed Torridonian rocks of Islay are really Dalradian, since he believed that ' they are earlier than the earth movements which metamorphose the Dalradian but not the Torridon Sandstone.' G. L. Elles and C. E. Tilley consider the Bowmore Sandstone to be non-metamorphosed Eilde Flags (*i.e.* Moine Series), thus agreeing in some measure with Barrow, Gregory and Green, but on the other hand, they accept the Loch Skerrols Thrust.

Almost the whole of Colonsay is composed of rocks confidently considered to be Torridonian (Fig. 2). The succession is as follows:

8. Staosnaig Phyllite Group: dark phyllites.

7. Colonsay Limestone Group: dark sandy limstone on east coast; two limestones separated by dark phyllites and flags at Kiloran Bay.

6. Kiloran Flag Group: very uniform and constant.

5. Milbuie Group: epidotic grits, grits and phyllites.

4. Kilchattan Group: phyllite and sandstone, greatly varying.

3. Machrins Group: alternating grits and mudstones.

2. Dun Gallain Group: epidotic grits, in places interdigitating with Group 3.

1. Oronsay Group: sandstones below, mudstones above.

The thickness of the sediments probably exceeds 5,000 ft. The metamorphism of the rocks is not high, the beds being folded and cleaved but not recrystallized. The Colonsay rocks show two distinct cleavages, the earlier a slaty cleavage, the later of strain-slip type. The earth-movements, presumably of Caledonian date, which produced these two cleavages were separated by a period of igneous activity, during which small syenite and diorite masses and many lamprophyre dykes were intruded. The Colonsay sediments dip east and north-east at gentle angles and, in the extreme north of the island, the upper portion of the beds forms a synclinal basin flanked by two anticlines. In conglomerates at the north end of the island pebbles resembling the Islay Dalradian Quartzite have been found.

B. N. Peach (1930) has correlated the Colonsay and Islay rocks, the most important item of this being the suggested equivalence of the Colonsay Limestone Group (7 of table above) with the Islay Limestone of the Dalradian Formation. E. B. Bailey and W. B. Wright, the authors of the Colonsay Memoir, had already shown, however, that such a correlation was extremely unlikely, the stratigraphical contrasts being briefly stated thus:—

Portaskaig Conglomerate	Black Phyllite
Islay Limestone	Colonsay Limestone
Grey Phyllites	Flags

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IV. HIGHLAND SCHISTS

THIS GROUP OF rocks is the most important in the Grampian Highlands. It may conveniently be considered in two divisions:—

1. Moine Series (Central Highland Granulites).
2. Dalradian Series.

1. Moine Series (Central Highland Granulites)

The close similarity of the flaggy rocks of the Garry valley about Struan (Strowan or Struan Flags) to the Moine granulites of Sutherland and Ross was clearly demonstrated by G. Barrow. The definite correlation of the uniform granulites and pelitic schists which cover great areas in the Spey valley, etc., with the Moine Series of the Northern Highlands has been accepted by most Scottish geologists, but it is perhaps advisable to use the alternative title, Central Highland Granulites, as well.

Central Highland Granulites and associated pelitic gneisses form the country-rock in the Findhorn valley, Strath Spey, about the headwaters of the Dee, Garry and Tummel, and in Glen Orchy and Glen Spean. They are bounded on the south and east by rock-groups classed with the Dalradian.

The chief rock-types are : (1) siliceous granulites, composed mainly of quartz, with varying amounts of feldspars—potash-feldspars and acid plagioclase—and small quantities of mica, chiefly biotite. Such rocks represent metamorphosed sandstones (Pl. IIIA); (2) muscovite-biotite-gneiss, often garnetiferous (pelitic gneiss), representing metamorphosed shales; (3) semipelitic rocks intermediate in composition between the two varieties just noted. This type of sediment is very widespread; it is a grey banded rock, often with muscovite-rich surfaces, and provides the 'flags' of Moine type; (4) a quite subordinate but very widespread rock-type is zoisite-granulite, composed of quartz, feldspar, zoisite, garnet and hornblende, and representing metamorphosed marls; (5) limestones are exceedingly rare in the Moine Series. White marbles and greenish calc-silicate-rocks, 20 to 25 ft. thick, occur near Kincraig House (Sheet 74), and again at Kyllachy House, Strathdearn (Sheet 74). In both cases, hornblende-schists are closely associated with the limestones; (6) a remarkable granulite, containing aegirine, is found in Glen Lui (Sheet 65); it is possibly derived from an acid alkaline igneous rock.

The Central Highland Granulites are thoroughly crystalline rocks, but occasionally show remains of quartz and feldspar pebbles. Although they have a deceptive general dip, resulting from isoclinal folding, they must be of great thickness. Sir J. S. Flett suggested that they were of continental formation.

In the Lochaber district rocks of the Moine Series have been styled Eilde Flags by E. B. Bailey (*see* p. 26). R. G. Carruthers has subdivided the rocks next to the Glencoe Quartzite (Dalradian) of this region into eleven groups of schists, quartzites and granulites, some of which he classes with the Moine Series (Corrour Granulites, Loch Treig Schists, Reservoir Flags and Quartzite: *see* p. 26 and Plate V).

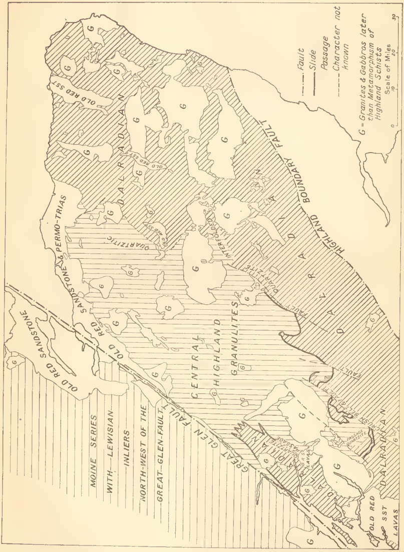


FIG. 4.—*The Marginal Relations of the Central Highland Granulites.*

The relation of the Moine Series to the Dalradian is a question of great difficulty (Fig. 4). In a broad way, the Dalradian rocks found next to the Moine Series are quartzitic in character, whilst the adjacent margin of the Moine Series is often itself very siliceous, a conjunction leading to differences in interpretation. In Lochaber and Glen Orchy, E. B. Bailey at one time linked the Eilde Flags (Moine) and Glencoe Quartzite (Dalradian) and a similar transition (complicated by his extended succession and suggested overlap at the margin of the Eilde Flags) is favoured by

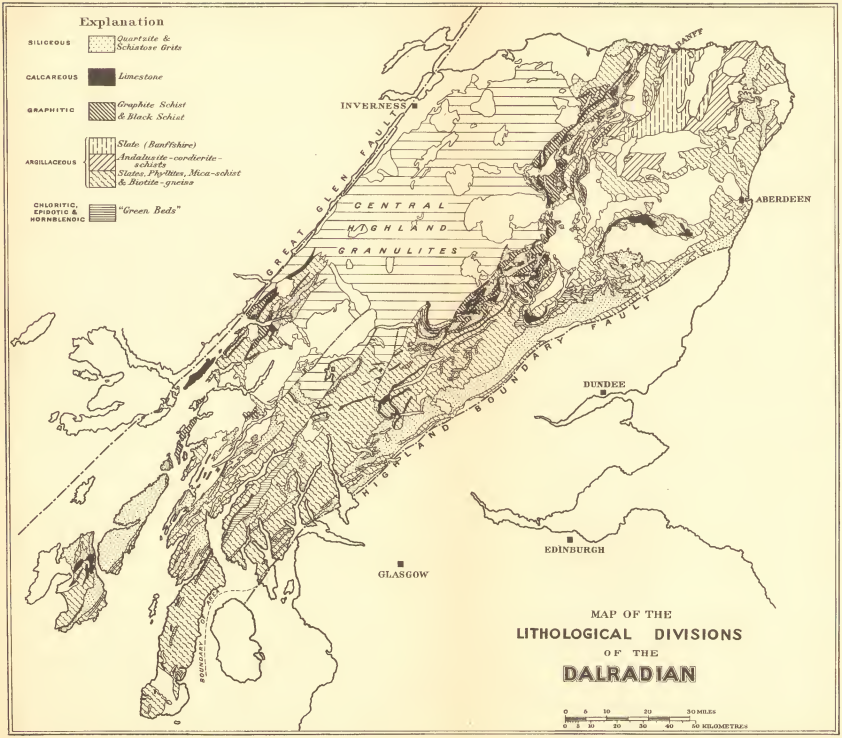
R. G. Carruthers. Farther east in Glen Lyon and around Loch Rannoch (Sheet 54) a structural break was suggested by L. W. Hinxman and M. Macgregor, whilst something of the same kind seems to be demanded by the relations seen at Schichallion as mapped by E. M. Anderson (*see also* p. 33). In the Upper Dee the Moine and Dalradian margin was considered by E. H. Cunningham-Craig to be interfolded. Farther north the margin of the Moine Series becomes quartzose and gives place to a broad belt of nearly pure quartzite. This quartzite is presumably that of Ben Aigan near Rothes. The Ben Aigan quartzite is the equivalent of the Cullen Quartzite of the Banffshire Coast which H. H. Read has linked with the Dalradian. Possibly, then, the Moine Series is transitional to the Dalradian through the quartzose phases just mentioned. J. W. Gregory regarded the Dalradian as lying unconformably on the Moine Series, advancing in favour of this view the celebrated Glen Tilt sections (*see* after), and the behaviour of the two formations where affected by the great north-north-east to south-south-west faults.

The views of G. Barrow on the relation of the Moine and Dalradian series were quite different from those already indicated. He maintained that the Moine rocks or Struan Flags pass eastwards into the Honestones, which are a thin division of the Dalradian Series, occurring between the Central Highland Quartzite and the Blair Atholl Limestone (*see* below). The critical section for Barrow's view is that of Gilbert's Bridge, Glen Tilt, where the Struan Flags are regarded as being repeatedly infolded with the Blair Atholl Limestone. This section, however, is interpreted by E. B. Bailey as Struan Flags in juxtaposition (possibly mechanical) with a series of intercalated metamorphosed calcareous sandstones, calcareous shales and limestones, belonging to the Blair Atholl Series of the Dalradian; further, Bailey questions the validity of the alleged unconformity of Blair Atholl Limestone on Struan Flags employed by Barrow and by Gregory; according to him, the discordance might as well be mechanical as stratigraphical, whilst, in any case, the so-called Struan Flags of this section really belong to the Blair Atholl Limestone Series of the Dalradian (Bailey, 1925).

2. Dalradian Series

The north-eastern, eastern and south-western portions of the Grampian Highland area are occupied for the most part by a great series of metamorphic rocks, mostly of sedimentary origin, to which the name Dalradian was applied by Sir Archibald Geikie in 1891. They comprise innumerable varieties of metamorphic types—quartzites and schistose grits, limestones and calc-silicate rocks, slates, phyllites, mica-schists, gneisses, black schists, etc. (Pls. II, IIIb, IV and V).

Absence of reliable data from which to deduce the original order of deposition of strata was the main cause of the controversies that characterized Dalradian geology from 1890 to 1930. Lack of this essential key led to widely different interpretations of local successions, of tectonics and of the distribution of metamorphic zones. A new era started in 1930 when T. Vogt brought to Scotland the criterion of current-bedding, and it was used to demonstrate steeply packed folding in the *inverted* limb of an extensive recumbent fold (Vogt, 1930; Bailey, 1930). Other criteria of the relative ages of successive beds have been extensively used since then (p. 27). The



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results of stratigraphical research during the last fifteen years have made it possible to omit from this edition the details of a number of outworn hypotheses. Controversy on Dalradian problems is by no means over; there is now, however, a definite prospect of careful field work producing a body of facts on which generally acceptable tectonic and metamorphic hypotheses may be based.

Some explanation is necessary regarding the stratigraphical units, such as Ben Lui Garnetiferous Mica-schist, etc., named below in the tabular statements of local successions; they are in many cases groups of strata composed of inter-stratified and inter-folded metamorphic rocks of various types, among which the rock named is considered to be dominant at the type locality. The same name may be applied in another district to strata differing in metamorphic grade and to some extent in sedimentary facies. Herein lies a major difficulty of Highland geology. Further trouble has been caused by one or more transferences of the same outcrop to a differently named stratigraphical unit, group, or series. Groups and series are usually markedly heterogeneous. A group is often a sub-division of a series, but these two terms have not been used consistently.

(*a*) LOCAL INTERPRETATIONS OF SUCCESSION

Starting from Central Perthshire the stratigraphy of the Dalradian rocks will be followed north-eastwards to the Banffshire coast and then (p. 20) south-westwards to Islay.

For the *central parts of the Grampian Highlands*, the broad general successions of the Dalradian agree in the main with that proposed in 1891 by Geikie, and based on the field-work of G. Barrow and others. This agreement most likely arises from the fact that the area in question is a tectonic unit through which run a few well-characterized stratigraphical horizons, chief among these being the Loch Tay Limestone. Geikie's 1891 succession is given in the following column; the names of many of the groups are later than Geikie, but have been accepted by all Highland geologists. According to Geikie, Barrow and others, the succession as given is in reversed stratigraphical order, the Leny Grits being considered to be the oldest group.

Original and Modified Standard Perthshire Successions

A. Geikie 1891	Peach—Henderson—Anderson 1930—1938—1942 (In Stratigraphical order: youngest beds at top)
Leny Grits	
Aberfoyle Slates	
Ben Ledi Grits	Leny and Ben Ledi Grits
Green Beds (epidotic, chloritic and hornblendic schists and schistose grits)	Green Beds (epidotic, chloritic and hornblendic schists and schistose grits)
Pitlochry Grits and Schists	Pitlochry Schists and Aberfoyle Slates
Loch Tay Limestone	Loch Tay Limestone
Ben Lui Garnetiferous Mica-schists	Ben Lui Garnetiferous Mica-schists
Ben Lawers Calcareous Schists	Ben Lawers Calcareous Schists
Ben Eagach Black Schists	Ben Eagach Black Schists
Central Highland (or Perthshire) Quartzite	Central Highland (or Perthshire) Quartzite
Blair Atholl Series	Blair Atholl Series

Owing to local evidence of current- and graded-bedding, the validity of part of Geikie's succession, and its stratigraphical order, have been questioned. According to S. M. K. Henderson (1938): (1) The Leny Grits are to be correlated with the Ben Ledi Grits, and (2) The Aberfoyle Slates are older than the Leny and Ben Ledi Grits; according to J. G. C. Anderson (1942): (3) The Pitlochry Schists are older than the Ben Ledi Grits, and (4) The Pitlochry Schists, as Peach believed (1930, Pl. xviii), may be equivalent to the Aberfoyle Slates and Dunoon Phyllites (p. 22). The succession modified in accordance with these views is tabulated above.

The Blair Atholl Series of the above succession was divided by G. Barrow as follows:—

Barrow's Subdivisions of the Blair Atholl Series

Honestones, passing laterally into the Struan Flags or Central Highland Granulites or Moine Series.	
Little (Tremolite) Limestone	sometimes eroded away
Dark Schist with Twinned Chlorite Rock and Felspar Rock	
Schichallion Boulder Bed	
Main Blair Atholl Limestone	
Calc-flintas	

This succession, in which Barrow placed the Honestones at the bottom of his sequence and the Calc-flintas at the top, is now out of date; and his correlation of Honestones with the Moine Series is only of historic interest (pp. 16, 30).

Two further elaborations of the Perthshire succession due to E. M. Anderson, E. B. Bailey, and W. J. McCallien, are tabulated below.

Schichallion and Central Perthshire

(In stratigraphical order: youngest beds at top)

E. M. Anderson 1925	E. B. Bailey and W. J. McCallien 1937		
Loch Tay Limestone	Loch Tay Limestone		
Ben Lui Garnetiferous Mica-schists	Ben Lui Garnetiferous Mica-schists		
Ben Lawers Calcareous Schists	Ben Lawers Calcareous Schists		
Ben Eagach Black Schists	Ben Eagach Black Schists		
Carn Mairg Quartzite	Carn Mairg Quartzite		Perthshire Quartzite Series
Killiecrankie Schists	Killiecrankie Schists		
Schichallion Quartzite (with intercalated boulder bed)	Schichallion Quartzite (with intercalated Dolomitic Beds and some conglomerate)		
Main Boulder Bed	Schichallion Boulder Bed	Pale Group	Blair Atholl Series
White Limestone	White Limestone		
Banded Series	Banded Group		
Grey Limestone	Grey Limestone	Dark Group	
Grey Schist	Dark Schist		

The sub-division of the Perthshire Quartzite and Blair Atholl Limestone Series is based on the Schichallion area. Bailey (1925, 1928) has, however, followed most of his subdivisions (but not the Dolomitic Beds intercalated in the Schichallion Quartzite) as far north-east as Braemar on the River Dee in Aberdeenshire. Bailey and McCallien regard the Dolomitic Beds as analogous to the Dolomitic Group of North Islay (p. 25) but according to Anderson the outcrops concerned are parts of the Grey Blair Atholl Limestone. Apart from this point there is agreement and the three authors believe that the succession is a stratigraphical one with the Loch Tay Limestone at the top. Anderson shows the additional upward sequence: Loch Tay Limestone—Pitlochry Schists—Green Beds—Ben Ledi Grits.

This agreement has been reached after years of controversy (pp. 30–31), of which further details may be found in the first edition of this Regional Guide (Read, 1935) and elsewhere (Bailey, 1925).

The 1891 succession of Geikie slightly modified according to the views of Peach, Henderson and J. G. C. Anderson, may therefore be taken as that most probable for the Central Dalradian area, *i.e.*, from Campbeltown in Kintyre to Glen Clova in Forfarshire (Angus).

When an attempt is made to extend this sequence into the more remote portions of the Dalradian outcrop, difficulties are encountered and opinions have differed widely. Its extension northwards into *Aberdeenshire and Banffshire* may be discussed first. H. H. Read (1928) has advocated the correlation of the Deeside Limestone of Deeside with the Loch Tay Limestone on the grounds of their agreement in general lithological character, structural position, and position with regard to zones of concordant acid and basic intrusions. The Deeside Limestone marks a north-easterly extension of the 'Loch Tay Inversion' zone (*see* p. 32), and near Aboyne in Aberdeenshire it lies in a localized 'flat belt.' Read's divisions of the Deeside Schists and his suggested correlations with the Central Perthshire sequence are given in the columns below:—

Correlation of the Deeside Schists with the Perthshire Sequence

Middle Deeside and Glen Muick (H. H. Read)	*Standard Sequence of Central Perthshire*
Glen Tanner Quartzite and Mica-schist Group	Pitlochry Grits and Schists
Deeside Limestone	Loch Tay Limestone
Queen's Hill Quartzite and Mica-schist Group	Ben Lui Garnetiferous Mica-schists

This correlation is completely opposed to the views of G. Barrow, who considered the Deeside Schists to be the very lowest rocks in the Highlands, being brought up by a fault of great magnitude. This question has been fully discussed by Read (1928).

For the Dalradian area north of Deeside the standard section is that of the Banffshire coast described by H. H. Read (*see* Pl. IV). The rocks have been divided into two divisions, the Banff Division and the Keith Division. The further subdivisions are shown in the left-hand column of the table on p. 21.

Two correlations of quite different type have been advanced, one by Read and one by J. Horne; these correlations are set out in the table on p. 21. Read considers that the Keith Division can be correlated with some certainty with the Standard Perthshire Succession of Geikie and Barrow, but that the Banff Division is not directly equivalent to any Perthshire groups. In lithology and, as mentioned later, in tectonic position the Banff Division recalls the Loch Awe Assemblage of E. B. Bailey. These suggestions were rejected by J. Horne, who held that the Loch Tay Limestone was represented in Banffshire by the Boyne Limestone, and that the other members of the Banff Division were equivalent in a general way to the Perthshire groups occurring to the south-east of the Loch Tay Limestone. Read has pointed out that there is no representative in Banffshire of that persistent Perthshire group, the Green Beds.

There is agreement between Read and Horne on the essential unity of the Banff Division and of the Keith Division, each division taken by itself, while Horne further held that both divisions form one great continuous succession. An entirely different reading and correlation of the Banffshire coast-section has been advanced by J. W. Gregory; but Read (1936) has shown: (1) by evidence which includes observations of current-bedding, that the stratigraphical order in the Keith Division is from the Cullen Quartzite in the west, upwards to the Cowhythe Gneiss in the east; (2) by evidence which includes observations of graded-bedding, that the stratigraphical order in the Banff Division is from the Boyne Limestone in the west, upwards to the Macduff Slates and Grits in the east. It is therefore unnecessary to reproduce the details of Gregory's reading of the succession (*see* Read, 1935).

Gregory placed the Macduff Group of the Banffshire coast-section in the *Lennoxian*, and the question of the existence of this series may now be examined. The Leny Grits and Aberfoyle Slates of Geikie's Dalradian sucession, and the rocks of other areas considered to be equivalent to these two groups, were detached from the Dalradian by J. W. Gregory and taken to form a new series, the *Lennoxian*, of post-Dalradian age. Gregory based the separate existence of the Lennoxian on the following alleged evidence: the lower grade of metamorphism of the Lennoxian; the abrupt change from the Lennoxian to the Dalradian all across Scotland; the occurrence of Dalradian fragments in the Lennoxian grits and conglomerates; and the absence from the Lennoxian of the epidiorite (Older Basic) sills characteristic of the Dalradian. The Lennoxian was thus post-Dalradian, and Gregory suggested it was also pre-Torridonian.

It is a difficult matter to discuss the validity of the Lennoxian as a post-Dalradian series, for Gregory presented little definite evidence in support of his views and admitted that the unconformity between Lennoxian and Dalradian is nowhere seen. On the shore at Banff, according to H. H. Read, the unity of the Dalradian and the supposed unconformable Lennoxian can be demonstrated in half an hour (*for details see* Read, 1935). At present no working Highland geologist admits the existence of the Lennoxian as an independent post-Dalradian formation.

The paragraphs that follow are devoted to *local successions in the South-west Highlands*. It will be shown later (p. 31) that E. B. Bailey divides these rocks into three structural units which, from below upwards, are the Ballappel (Ballachulish—Appin—Loch Eilde) Foundation, the Iltay (Islay—Loch Tay) Nappe, and the Loch Awe Assemblage (Pl. V). The Loch Awe Assemblage, which Bailey formerly regarded as a separate nappe, is now incorporated in his Iltay Nappe (p. 32). No agreement has been reached on the correlation of the Dalradian rocks of the Ballappel Foundation with those of the Standard Perthshire Succession; accordingly the Ballachulish—Appin district is dealt with at the end.

The stratigraphy of the north-easterly part of the Iltay Nappe-complex (p. 31) has already been considered, starting from Central Perthshire where the rocks were first mapped in detail. We shall now pass south-westwards from Central Perthshire, following roughly the sequence of investigation in

The Banffshire Coast-section and the Two Correlations

	Dalradian Succession of the Banffshire Coast (H. H. Read)	*Read's Correlation with Perthshire*	*J. Horne's Correlation with Perthshire*
Banff Division	Macduff Slates and Pebbly Grits		Aberfoyle Slates
	Boyndie Bay Group (andalusite-schists and pebbly grits)	The Banff Division is not directly equivalent to any Perthshire groups. In lithology and possibly in tectonic position it recalls the Loch Awe rocks	Ben Ledi Grits
	Whitehills Group (pebbly grits, pebbly limestones, phyllites)		Pitlochry Grits and Schists
	Boyne Limestone		Loch Tay Limestone
	The Boyne Line (discordance)		
Keith Division	Cowhythe Gneiss	Ben Lawers Schists	
	Portsoy Group (limestone, graphite-schists and mica-schists)	Ben Eagach Black Schists	
	Durn Hill Quartzite	Central Highland Quartzite	
	Sandend Black Schist and Limestone Group	Blair Atholl Series	
	Garron Point Actinolite-schist		
	Crathie Point Calcareous Flags		
	Findlater Flags		
	West Sands Garnetiferous Mica-schists		
	Cullen Quartzite: Logie Head Beds; flaggy		
	Cullen Quartzite: Findochty Beds; massive		

the Iltay Nappe-complex in Cowal, North Kintyre and Knapdale, the Loch Awe region, and the Islay—Jura archipelago.

For *Cowal, North Kintyre and Knapdale*, the following successions have been given by C. T. Clough and others; the customary correlations with the Standard Perthshire Succession are shown in the right-hand column.

Cowal Succession C. T. Clough	*North Kintyre Succession* G. S. Memoir Sheet 28	*Perthshire Succession*
Phyllites and Schistose Pebbly Grits		Leny Grits
Bull Rock Greywacke Schist		
Dunoon Phyllites		Aberfoyle Slates
Beinn Bheula Grits and Schists	Beinn Bheula Schists	Ben Ledi Grits
Green Beds	Green Beds	Green Beds
Glen Sluan Schists and Grits, albite-schists, etc.	Glen Sluan Schists	Pitlochry Grits and Schists
Loch Tay Limestone	Loch Tay Limestone	Loch Tay Limestone
Ben Lui Garnetiferous Mica-schists	Stonefield Schists	Ben Lui Garnetiferous Mica-schists
	Erins Quartzite and	
St. Catherine's Graphite-schist	Stronchullin Phyllites	
Ardrishaig Phyllites	Ardrishaig Phyllites	Ben Lawers Schists

In considering the correlations with Central Perthshire in the above tables, the reader should remember that modern evidence points to the probable stratigraphical identity of the Pitlochry Schists and the Aberfoyle Slates, and of the Ben Ledi Grits and the Leny Grits (p. 18). Of the localities mentioned, Bull Rock, Dunoon, Beinn Bheula, Glen Sluan (Glensluan) and St. Catherine's are in Cowal; Ardrishaig, Stronchullin, Erins, and Stonefield are in Knapdale; the remainder are in Perthshire (*see* Pl. V).

North-west of the outcrop of the Loch Tay Limestone that, from Loch Tay to Campbeltown in Kintyre, forms a sure index position in the Dalradian succession, there are the celebrated Dalradian areas of Loch Awe, Islay and Jura, and Ballachulish. This ground has been the scene of E. B. Bailey's lengthy researches; his views of twenty-five years ago (1922), which on the whole were not accepted by other workers, have been very considerably modified as a result of further researches on the problem of stratigraphical order (pp. 27, 32). The main trends of the controversy may now be considered.

The original *Loch Awe Group* of J. B. Hill dealt with those rocks that followed on the side of the Ardrishaig Phyllites opposite to the Loch Tay Limestone side. As shown below, Hill proposed a three-fold division of grits and quartzites, slates and limestone. The basic igneous rocks that have since been shown by Peach and others to be of volcanic origin (*see* p. 39) were regarded as intrusive by Hill.

J. B. Hill's Loch Awe Succession

(In reverse stratigraphical order: oldest beds at top)

	Beinn Bheula Grits and Schists
	Green Beds
	Glen Sluan Schists
	Loch Tay Limestone
	Garnetiferous Mica-schist
	Graphite-schist
	Ardrishaig and Craignish Phyllites
Loch Awe Group	Limestone
	Slates, black, locally green
	Grits and quartzites, with local boulder-bed

According to E. B. Bailey, the Loch Awe rocks are formed of an upper series, the Loch Awe Group, and a lower series, the Ardrishaig Group. Bailey's grouping is given in the table below.

E. B. Bailey's Grouping of the Loch Awe Rocks

(In stratigraphical order: youngest beds at top)

Loch Awe Group	Loch Avich Green Slates and Grits, and (in basal part) Pillow Lavas
	Tayvallich Slates and Limestones, Grits, Conglomerates, and Pillow Lavas. Fragments in the conglomerates are usually local, but occasionally granite (' nordmarkite '), etc., are found
	Crinan Grits and Quartzites, with subordinate slates and limestones
Ardrishaig Group	Shira Limestone (local) often interbedded with greenish-grey phyllites
	Ardrishaig Phyllites (with calcareous lenticles, limestones and some fine-grained quartzites), St. Catherine's Graphite-schist (local) and Erins Quartzite (local, fine-grained)

Bailey formerly maintained, for structural reasons, that the Ardrishaig and Craignish Phyllites are not the equivalents of the Ben Lawers Schists of the Standard Perthshire Succession. In 1936, however, he accepted this correlation, which involves the elimination of his slide separating his Loch Awe Nappe (now Loch Awe Assemblage) and his Iltay Nappe (p. 31). G. L. Elles and C. E. Tilley (1930, 1935) and J. F. N. Green (1931) have advocated the Ardrishaig—Ben Lawers correlation, but while Green accepted Bailey's stratigraphical order, Elles and Tilley (1930), and Elles (1935), favoured reversing it.

Allison has since claimed that the Tayvallich Limestone Group is demonstrably younger than the Crinan Grit and Quartzite Group, and this has led Tilley to accept Bailey's Loch Awe succession (Allison, 1940: discussion). Elles, in her detailed paper of 1935, in which she re-asserts the reversal of Bailey's sequence, stresses the stratigraphical importance of the Loch na Cille Boulder Bed. Allison, however (1940), regards the boulder bed as a xenolithic igneous rock.

Bailey, Elles, and Tilley formerly correlated the Crinan Quartzite with the Central Highland or Islay Quartzite. Tilley now doubts this correlation and Bailey tentatively follows Peach in equating the Crinan Grits, quartzites, etc., and the Ben Lui Schists, with the concomitant correlations of Tayvallich Limestone with Loch Tay Limestone, and Loch Avich Grits, Slates and Green Beds, with Pitlochry Schists and Green Beds (Bailey and Holtedahl, 1938; Allison, 1940: discussion). These proposals, if accepted, imply correlations on the following lines (cf. tables, pp. 22–25):

(In stratigraphical order: youngest beds at top)

Loch Awe	*Perthshire*
Loch Avich Grits, etc.	Leny and Ben Ledi Grits
Loch Avich Lava Group	Green Beds
Tayvallich Slates and Lavas	Aberfoyle Slates and Pitlochry Schists
Tayvallich Limestone, etc.	Loch Tay Limestone
Crinan Grits and Slates, etc.	Ben Lui Garnetiferous Mica-schists
Shira Limestone	Ben Lawers Calcareous Schists
Ardrishaig Phyllites	
Easdale Slates	Ben Eagach Black Schists

In the *Islay–Jura archipelago* (Fig. 2), the successions of Peach and of Bailey given below show a general resemblance, except, of course, for Peach's suggestions concerning the equivalence of the Dalradian rocks of this area with Torridonian and Cambrian. Bailey has given correlations of his Islay succession and the Standard Perthshire Succession (p. 25).

Successions in the Islay Archipelago

(In stratigraphical order: youngest beds at top)

	B. N. Peach (1930)	E. B. Bailey (1917)	
? Cambrian	Pebbly Quartzite, etc., of Scarba, Q4, with blocks of limestone, slate, felsite, granite (Local Erosion)	Ardmore and Laphroaig Quartzites	
	Port Ellen Beds	Port Ellen Phyllites, grey	
		Scarba Conglomeratic Group	Islay Quartzite
		Jura Slate, black and grey	
	Rudh' a' Mhàil Quartzite, Q3	Main Quartzite	
	Upper 'Fucoid' Beds		
	Pipe Rock Quartzite, Q2	Dolomitic Group of North Islay	
	Lower 'Fucoid' Beds: dolomitic shales and flags		
	Local conglomeratic top of Quartzite, Q1	Upper Conglomerate of North Islay	
	Lower or Fine-grained Quartzite, Q1	Lower fine-grained Quartzite of North Islay	
	Portaskaig Conglomerate, some bands of sandy dolomite	Portaskaig Conglomerate	
? Torridonian	Islay Limestone and Phyllite Group	Islay Limestone and Garvellach Dolomite (locally oolitic; in part interbedded with Mull of Oa Phyllites)	
		Mull of Oa Phyllites, grey, sometimes with thin sandy dolomites	
		Maol an Fhithich Quartzite, fine-grained	

J. F. N. Green at one time (1924, 1931; *see also* Read, 1935) reversed Bailey's stratigraphical sequence in Islay and Jura, and included in the Dalradian a portion of the Bowmore Sandstone Group, as already noted. In 1933, however, A. Allison confirmed Bailey's Dalradian succession in detail and Green, after revisiting the area, admitted that the evidence favours Bailey and Allison (Allison, 1933: discussion; Bailey, 1934: discussion).

All observers so far mentioned recognize two horizons of conglomeratic materials, the Portaskaig (or Port Askaig) Conglomerate and the Scarba Conglomerate, or Conglomeratic Group, on the two sides of the Islay Quartzite. S. B. Wilkinson in the Islay Memoir of 1907 considered these two conglomeratic groups to be one and the same, and was followed in this view by Gregory. In consequence of Allison's work, Gregory's views (*see* Read, 1935) need not be repeated here.

In 1922 Bailey gave a *general statement of the succession in the Iltay Nappe;* in part it was based on the Standard Perthshire Succession and in part on Islay, Jura, Scarba, etc. The sequence in the Loch Awe region was excluded because at that time Bailey regarded these beds as belonging to a separate nappe. The succession and its correlation with Perthshire were included in the first edition of this Regional Guide (Read, 1935). It will be more useful here to give a new table, based on Bailey's and Allison's succession for Islay and Jura (1917, 1933) combined with Bailey's Loch Awe

(*C*.2296)

A.—River Lyon, near Gualann
[For explanation, *see* p. viii]

(*C*.1762)

B.—Sgurr a' Mhaim, Mamore Forest
(For explanation, *see* p. viii)

(*C.*1484)

A.—Bow Fiddle, Portknockie, Banffshire
[For explanation, *see* p. viii]

(*C.*1508)

B.—Boyne Bay, Portsoy, Banffshire
[For explanation, *see* p. viii]

Succession (1913), and to show the probable or possible correlations with the Perthshire Succession amended according to the latest suggestions (pp. 17–18).

Iltay Succession

(In stratigraphical order: youngest beds at top)

	Islay and Loch Awe		Perthshire (Schichallion)
Loch Awe Syncline	Loch Avich Grits, etc. Loch Avich Lava Group Tayvallich Slates and Lavas		Leny and Ben Ledi Grits Green Beds Aberfoyle Slates and Pitlochry Schists
Loch Awe Syncline	Tayvallich Limestone, etc.		Loch Tay Limestone
Loch Awe Syncline	Crinan Grits and Slates, etc.		Ben Lui Garnetiferous Mica-schists
Loch Awe Syncline	Shira Limestone Ardrishaig Phyllites		Ben Lawers Calcareous Schists
Islay, Jura, Scarba, Luing, etc.	Easdale Slates		Ben Eagach Black Schists
Islay, Jura, Scarba, Luing, etc.	Scarba Transition Group: Port Ellen Phyllites; Slates; Ardmore and Laphroaig Quartzites, etc.		
Islay, Jura, Scarba, Luing, etc.	Scarba Conglomeratic Group Jura Slates Main Quartzite Dolomitic Group Upper Conglomerate Lower Quartzite	Islay Quartzite	Perthshire Quartzite Series: Pebbly Quartzite Killiecrankie Schists Quartzite Dolomitic Beds[1] Conglomerate (local) Quartzite
Islay, Jura, Scarba, Luing, etc.	Portaskaig Conglomerate		Schichallion Boulder Bed[2]
Islay, Jura, Scarba, Luing, etc.	Islay Limestone: To some extent interbedded with Mull of Oa Phyllites: sometimes with thin sandy dolomites Maol an Fhithich Quartzite		Blair Atholl Series

The above table is not intended to convey a definite correlation of individual units of the Islay Quartzite and Perthshire Quartzite Series. The equivalence of the Portaskaig Conglomerate and the Schichallion Boulder Bed was suggested by J. Macculloch in 1819. The glacial origin of the Portaskaig Conglomerate was advocated by J. Thomson in 1877, although he did not regard it as a product of land-ice; Bailey at one time (1917) expressed doubts as to its glacial origin. E. M. Anderson (1923) has suggested that the Schichallion Boulder Bed is a tillite (glacial ground-moraine); this hypothesis has been accepted by Bailey and McCallien (1937) with the proviso that the Boulder Bed is *included in an essentially conformable series of formations.* Granite (' nordmarkite ') boulders are numerous in both conglomerates. Holtedahl (1939) has suggested that the Schichallion Boulder Bed is probably equivalent to an Upper Sparagmitian tillite in Norway.

In the *Ballachulish area* the succession formerly advocated by Bailey (1922) has been modified in detail and its stratigraphical order has been reversed, with notable tectonic implications (p. 32). These changes resulted from the work of T. Vogt, followed by that of Bailey himself (p. 27). The extended sequence of quartzites and schists below the Glencoe Quartzite, originally advanced by R. G. Carruthers, has now been admitted *in*

[1] Regarded by E. M. Anderson as an infold of Blair Atholl Series (p. 18).
[2] Included by E. B. Bailey in Blair Atholl Series.

part and demonstrated afresh by Bailey. The details of the succession are set out below (*see also* pp. 15, 27).

The Ballachulish (Ballappel) Succession

E. B. Bailey (1922 with amendments of 1930, 1934, 1938)

(In stratigraphical order : youngest beds at top)

Lismore Limestone
Cuil Bay Slates, black
Appin Phyllites (or Mica-schists), often with much flaggy quartzite
Appin Limestone, dolomitic, sometimes with central band of quartzite and phyllite
Appin Quartzite, pebbly
Appin Striped Transition Series
Ballachulish Slates, black graphitic and pyritous
Ballachulish Limestone
- Dark grey or black Limestone
- Calcareous and quartzose Mica-schist
- Cream-coloured Limestone

Leven Schists
- Pelitic Series
- Banded Series

Glencoe Quartzite
Binnein Schist
Binnein Quartzite
Eilde Schist
Eilde Quartzite and Stob Quartzite
Eilde Flags (*Moinian*)

Below the Eilde Flags, R. G. Carruthers includes his Stob Quartzite and Reservoir Schists in the Lochaber Dalradian Series. The underlying series: Reservoir Quartzite, Reservoir Flags, Loch Treig Schists and Corrour Granulites (p. 15) he assigns to the Moinian. Carruthers believes, however, that above the Eilde Flags there is a marked overlap of successive groups. Many geologists regard the Moinian as continuing upwards so as to include the Eilde Flags (*see* 'Geology of Corrour and Moor of Rannoch,' *Mem. Geol. Surv.*, 1923, pp. 16–30). Bailey (1934) correlates the Stob and Eilde Quartzites on the evidence of false-bedding.

In 1922, Bailey tentatively correlated the above succession in *reversed stratigraphical order* with the Loch Awe and Iltay Nappes, equating the Appin, the Islay and Shira Limestones. H. H. Read has suggested that the Ballachulish Limestone is more likely to be representative of the Blair Atholl Limestone of Perthshire, which is generally regarded as the equivalent of the Islay Limestone (Read, 1923, in *Mem. Geol. Surv.*, Sheets 86 and 96). Bailey now considers (1934, 1938) that if the Ballachulish succession corresponds at all to the Islay and Perthshire successions, the Appin and Lismore Limestones are most likely to be equivalent to limestones in the Blair Atholl Series of Perthshire (cf. table, p. 18).

A very different succession for the Ballachulish rocks was favoured by J. F. N. Green, who held, for example, that the Appin Limestone represents part of the Ballachulish Limestone of Bailey, and that the Cuil Bay Slates, Appin Phyllites, Leven Schists and Eilde Flags are equivalent groups (1931).

Bailey's type-section for the succession in the Ballachulish area is that on the Onich shore, where the beds are clearly seen repeated on the two limbs of a fold. Bailey's reading of this section has been investigated and admitted by dozens of geologists. It is not necessarily correct because of this, but any modification requires more detailed work than has yet been done by its critics.

(*b*) STRATIGRAPHICAL ORDER

Broadly speaking, there are or have been two views concerning the stratigraphical order of the Iltay Dalradian rocks. A. Geikie, G. Barrow, E. H. Cunningham-Craig and J. S. G. Wilson, J. W. Gregory and J. F. N. Green regarded the Leny Grits (or Ben Ledi Grits if the Lennoxian is taken as a separate post-Dalradian series) as the oldest Dalradian group. The remainder of the authors who have expressed opinions on this subject, *e.g.*, E. B. Bailey, E. M. Anderson, B. N. Peach, G. L. Elles, C. E. Tilley, S. M. K. Henderson and J. G. C. Anderson, consider the Leny Grits or their equivalents to be the youngest group. The question has really been connected with the style of tectonics favoured by individuals. If large-scale inversions of portions of the Dalradian sequence were considered to be impossible, then order of superposition was taken to be the same as order of deposition; the Leny Grits and adjacent groups in the Perthshire area pass beneath the Loch Tay Limestone, and were therefore considered to be older. On the other hand, if the possibility of large-scale inversions is admitted, then the structural sequence does not necessarily coincide with the stratigraphical sequence, and new lines of attack on the problem have to be elaborated.

Apart from early suggestions by J. S. G. Wilson, E. B. Bailey and others, the modern attack was initiated by T. Vogt, who, in 1930, used the evidence afforded by current-bedding to show that the stratigraphical sequence in the Ballachulish district begins with the Glencoe Quartzite at the bottom and passes up to the Appin Phyllites at the top. Bailey (1930) confirmed and extended Vogt's observations in the Ballachulish area, and demonstrated that part of Carruthers' extended sequence of quartzites and schists beneath the Glencoe Quartzite (Binnein Schists to Eilde Flags), already referred to on p. 26, was correct. Bailey (1930), by using both current-bedding and graded-bedding, also investigated the stratigraphical order in other areas of the Dalradian. On the evidence of graded-bedding, the Ben Eagach Black Schists of Perthshire were shown to be younger than the Central Highland Quartzite, and, in the Loch Awe region, the Crinan Quartzite to be later than the Shira Limestone. The new methods have been applied in convincing manner by A. Allison (1933) in Islay and Jura, confirming in detail the original stratigraphical succession advanced by Bailey for the Dalradian rocks. Allison (1940), using graded-bedding, has also shown that the Tayvallich Limestone Group is younger than the Crinan Grit and Quartzite Group; this evidence, coupled with his careful study of stratigraphy and folding, has led to a fairly general acceptance of Bailey's Loch Awe succession. In the Cruachan district, J. G. C. Anderson has confirmed the stratigraphical order for portions of the Ballachulish and Islay successions (1935). Other recent work of Anderson's concerns the stratigraphical order of Dalradian Schists near the Highland Boundary Fault (1942, 1945) (*see also* p. 18). H. H. Read (1936) has confirmed his own earlier views on the Dalradian Succession of the Banffshire coast (p. 21). This was done by observing current-bedding and graded-bedding. He has shown how original graded-bedding may be detected even in totally re-crystallized garnet-staurolite-andalusite schists.

(c) METAMORPHISM AND METAMORPHIC ZONES

The original sediments of the Dalradian Formation have been subjected to regional metamorphism varying in type in different areas. Apart from any geochemical migration connected with the formation of migmatites, the resulting products depend upon three factors: (1) the chemical composition of the original rock, (2) the temperature and (3) the pressure. In rocks of similar compositions the variations of temperature and pressure lead to the formation of different assemblages of minerals which can be arranged in an order or orders of increasing metamorphic grade. Similarly, rocks of different original compositions affected by the same temperature and pressure conditions give rise to different mineral assemblages. G. Barrow first drew attention to one aspect of this reaction to varying physical conditions when in 1893 he mapped out lines in the South-east Highlands marked by the *incoming* of certain index minerals in pelitic or argillaceous sediments (Fig. 5). The zones eventually established by Barrow for the South-east Highlands were: (1) Lowest Grade —*Zone of Clastic Mica*, with a very limited development close to the Highland Boundary Fault, (2) *Zone of Digested Mica*, (3) *Zone of Biotite*, (4) *Zone of Garnet*, (5) *Zone of Staurolite*, (6) *Zone of Kyanite*, (7) *Zone of Sillimanite*. Later work by C. E. Tilley (1925) has led to some modifications of Barrow's zones. Using the index minerals, *Chlorite*, *Biotite* and *Almandine-garnet*, he has traced the distribution of zones characterized by the entry of these minerals throughout much of the South-west Highlands, while more recently the same author and G. L. Elles (1930) have given a map of the South-west Highlands, including Islay and Jura, on which these metamorphic zones are laid down. Barrow considered the metamorphic zones to be of the nature of gigantic aureoles around intrusions of Older Granite (*see* later, p. 40), whilst H. H. Read (1927) suggests that the injection-phenomena of the Older Granite and the sillimanite-grade of the associated sediments are both localized effects of orogenic migmatization. In the South-west Highlands, E. B. Bailey (1923) employed different indices from those of Barrow or Tilley; he gave the following zones: (1) mica inconspicuous, (2) mica conspicuous and (3) (*a*) mica with garnet, (*b*) mica with albite. In agreement with E. H. Cunningham-Craig, Bailey considered garnet as an alternative metamorphism to albite, garnet being produced under more thermal, and albite under more hydrothermal, conditions of metamorphism. Bailey and McCallien (1934), in dealing with the formation of albite in Irish and Scottish schists, argue that the mineral is produced by the metamorphism of pelitic rocks containing detrital albite powder. Bailey[1] refers to analysed slates in Dutchess Co., New York State, which might be expected to give porphyroblastic albite-schist under appropriate metamorphic conditions. D. L. Reynolds, however (1942), proposes that the formation of the albite-schists of the South-west Highlands is to be connected with the introduction of sodium silicate during the production of migmatites by complex geochemical migration in the axial regions of recumbent folds (p. 42).

There is a considerable variance in the views regarding the time-relations of the metamorphism and the folding (described in next section). Bailey regards movement and metamorphism as practically contemporaneous.

[1] E. B. Bailey, 'American Gleanings,' *Trans. Geol. Soc. Glasgow*, vol. xx, pt. i, 1936, p. 10.

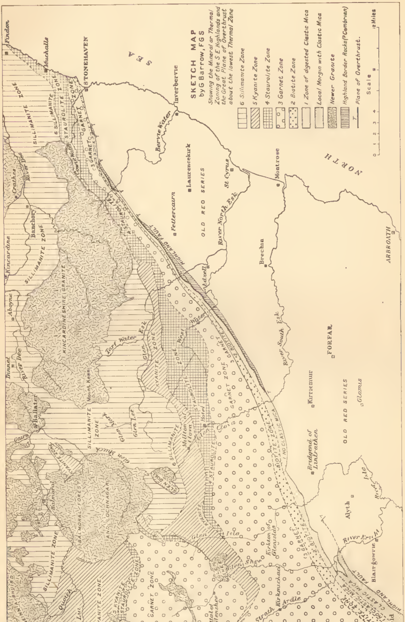

FIG. 5.—*Metamorphic Zones of the South-east Highlands, after G. Barrow.*

Elles and Tilley, on the other hand, at one time postulated widespread inversions of metamorphic zones (p. 34). Read (1940) suggests that the metamorphism is later than the large-scale movements, and that no inversion of metamorphic zones has taken place. Reynolds (1942) adopts the latter view, but supports F. E. Suess (1931) in regarding Dalradian metamorphism as syntectonic.

W. Q. Kennedy has recently published a composite map of Highland metamorphic zones, which he uses as evidence of a lateral displacement of sixty-five miles along the Great Glen Fault (1946, Fig. 5).

In the north-east, in Banffshire and Aberdeenshire, H. H. Read and others have described a progressive metamorphism of argillaceous rocks which gives rise to types not found in the Central Highlands. A central area of slate is there encircled by a belt of knotted slate and this by a gradual passage into andalusite-cordierite-schists. It may be suggested that the physical conditions of the andalusite-cordierite-metamorphism were not much different from those of the normal contact-aureole, *i.e.*, high temperature and relatively low directed pressure.

The mineralogical changes taking place in the Green Beds as they are traced from south-west to north-east, *i.e.*, from lower to higher zones, have been described by F. C. Phillips. Typical members of the series are in order, beginning with the lowest grade—chlorite-albite-epidote-schist, biotite-epidote-albite-schist, epidote-biotite-hornblende-schist, garnet-biotite-hornblende-schist, garnet-hornblende-schist and hornblende-biotite-plagioclase-schist.

(*d*) TECTONICS

Among the various interpretations of the structure of the Dalradian Series three types emerge more or less clearly; the first of these, which dispenses entirely with recumbent folding and sliding, is now disproved and virtually abandoned; the second, mainly developed by E. B. Bailey, has been so much modified that it now has a good deal in common with the third, advocated by B. N. Peach Both Bailey and Peach invoke recumbent folds and slides.

(1) Among the explanations which do not admit recumbent folding there were two main subgroups, one regarding the Central Highland Quartzite as interbedded in the Dalradian sequence, the other considering it as unconformable. The view of the interbedded quartzite was that presented by A. Geikie in 1891, and was based upon work by G. Barrow. According to this, the Dalradian rocks form a steady succession ascending north-westwards to the Blair Atholl Limestone. Difficulties in the distribution of metamorphic zones were met by Barrow's aureoles around the Older Granites. Barrow regarded the Struan Flags (Moine Series) as equivalent to the Honestones at the margin of the Central Highland Quartzite, there being a local unconformity 'below' the Boulder Bed. Another feature of Barrow's explanation was the invocation of 'concertina-structure,' the folding of these beds *upon themselves* until they come to cover vast areas: whilst isoclinal folding is admitted, 'concertina-structure' is rejected by practically all other Highland geologists. E. H. Cunningham-Craig's tectonics of the Perthshire ground were characterized by his views that the Ben Eagach Series is the equivalent of part of the Blair Atholl Series, and

that the Central Highland Quartzite lies in synclinal folds above a line of erosion, marking the position of the Boulder Bed, and along which the Quartzite is brought into contact with different members of the Black (Ben Eagach) Schist and (Blair Atholl) Limestone Group.

In J. F. N. Green's synthesis of the South-west Highlands (1931) the tectonics are devoid of large-scale structures and resolve themselves into gentle synclines and anticlines.

(2) The second view of Dalradian tectonics is based upon recumbent folding and sliding (fold-faulting). Sections of recumbent folds are shown in Fig. 7.

The chief exponent of this view is E. B. Bailey (1910, 1922), whose revision of the geology of much of the South and South-west Highlands followed on (1) Clough's 1897 interpretation of the Carrick Castle recumbent fold and the Cowal Anticline, and (2) H. B. Maufe's recognition, in 1905, of a huge recumbent overfold of quartzite in Glen Etive.

Bailey's revision covers most of the Dalradian rocks of the South and South-west Highlands (with locally associated Moine Schists) from Islay and Kintyre in the south-west to Ballachulish in the west, and Braemar in the north-east (Pl. V). His 1922 conception of Dalradian tectonics, in terms of the Ballappel (Ballachulish—Appin—Loch Eilde) Foundation, the Iltay (Islay—Loch Tay) Nappe, and the Loch Awe Nappe, has been greatly modified since 1930, when definite evidence on local stratigraphical successions began to be forthcoming (p. 27). In 1936, in a discussion following the reading of a paper by A. Allison (1940), he abandoned his 1922 hypothesis of a thrust, at the base of his ' Loch Awe Nappe,' separating Ardrishaig Phyllites and Ben Lawers Schists. He indicated that, for the district extending from Islay and Jura across Loch Fyne to Loch Lomond, he was prepared to accept, in principle, much of the alternative stratigraphical and structural interpretation advanced by B. N. Peach (1930, Pl. xviii). The present position may be summarized as follows.

Bailey still envisages the South and South-west Highlands as divided into three main structural divisions. These are, from below upwards, the Ballappel Foundation, the Iltay Nappe, and the Loch Awe Assemblage.

To the reviser it seems that the term nappe is no longer applicable to the Islay—Loch Tay Dalradian rocks. This seems clear from the section on Pl. V. ' Nappe-complex ' is suggested as a better description. This term will be employed in the text of subsequent paragraphs. Bailey's own nomenclature is, however, used on Pl. V, which is designed to illustrate his views.

The Ballappel Foundation, comprising in its upper portion the Appin Nappe and the overlying Ballachulish Nappe (both resting on slides) has been mapped in the area Glen Roy—Ben Doirean—Loch Creran. Rocks generally assigned to the Moine Schists or Moinian occur extensively below and in the Appin Nappe. Elsewhere the rocks are Dalradian.

The Iltay Nappe-complex of Dalradian rocks extends from Jura, Islay and Kintyre in Argyllshire, north-eastwards through Perthshire to Braemar in Aberdeenshire. West of a line Ardrishaig—Inverary—Dalmally, the main structures are broad and simple: the Loch Awe Syncline and the complementary Islay Anticline to the south-west.

Stratigraphically the Loch Awe Assemblage appears to be essentially identical with the Loch Awe Group ; but by ' assemblage ' Bailey here means ' structural assemblage within the Iltay Nappe-complex.' The Loch Awe Assemblage thus comprises beds of the Loch Awe Syncline that (*a*) are structurally the highest in the nappe-complex, and that (*b*) differ considerably in facies from their supposed stratigraphical equivalents east and north-east of Loch Fyne. This will be clear from the discussion of the structure of the Iltay Nappe-complex (*see below* and cf. Fig. 7, and Pl. V) and from the correlation table on p. 25.

Bailey regards the Ballappel Foundation as characterized by extensive recumbent folds. The reversal of the Ballachulish stratigraphical succession (p. 25) has led him (1930, 1934) to convert his original recumbent anticlines, closing towards the south-east, into recumbent synclines closing in the same direction. This implies that the overfolding or direction of movement of upper layers was here towards the *north-west* (not towards the south-east as he previously supposed) and that his main fold-faults or slides affect the *unreversed* limbs of recumbent folds and are thus ' lags ' (not ' thrusts ' as he previously supposed).

In the Iltay Nappe-complex, west of the line Ardrishaig—Inverary—Dalmally, recumbent folding is unknown, although the western limb of the Islay Anticline is overturned towards the north-west. The limbs of the broad Loch Awe Syncline and of the Islay Anticline are affected by numerous corrugations. Bailey's latest conception of the structure of the Dalradian rocks of the Iltay Nappe-complex, including the Loch Awe Assemblage, is shown diagrammatically in Fig. 7, Section A, based on his own sketch (1938). The Ben Lui recumbent syncline corresponds to the Pitlochry—Kirkmichael recumbent syncline (Fig. 7, Section B, based on Bailey, 1925, coloured Plate). Between Ben Lui and Pitlochry the presence of this recumbent syncline over a wide area in the Killin district is inferred by Bailey (1922, 1925) from Geological Survey mapping of a ' flat belt ' in which the Loch Tay Limestone is overlain by the Ben Lui Garnetiferous Mica-schists. This belt constitutes part of the ' Loch Tay Inversion ' zone (Pl. V) which can be traced from Kirkmichael north-eastwards to Deeside (*see* p. 19), and from Ben Lui south-westwards through Kintyre (Bailey, 1922). The Loch Awe Group of Bailey's succession (p. 23) thus corresponds to the unreversed upper limb of the recumbent anticline structurally overlying the Ben Lui—Kirkmichael recumbent syncline. This recumbent anticline, the upper limb of which has largely been removed by erosion, corresponds to the Carrick Castle recumbent anticline in Cowal, where however, the part of the fold which is preserved affects younger beds. Bailey's work from Schichallion to Braemar (1925, 1928, 1937) has led him to infer the presence, in the Iltay Nappe-complex in Perthshire and Aberdeenshire, of a number of large-scale recumbent folds and numerous slides, produced by the movement of upper layers towards the *south-east.* Most of the rocks involved are in the complex core-region of the major recumbent anticline structurally overlying the Pitlochry—Kirkmichael recumbent syncline (*e.g.*, Fig. 7, Section B).

In detail Bailey's tectonic interpretation, both in the Ballachulish and Perthshire—Aberdeenshire areas, is extremely complex. He envisages recumbently folded rocks, with associated slides, as having been bent into secondary[1] open or steep major and minor anticlines and synclines, and into secondary recumbent folds, all with gently pitching axes. The major open folds are the Cowal Anticline, Ben Lawers Syncline, Glen Orchy Anticline, Loch Awe Syncline, Islay Anticline and Glen Creran Syncline (Pl. V). Locally, as at Loch Leven and Schichallion, he infers that subsequent 'sideways' or 'twisting' movements were superimposed on this complex fold and slide system and produced in it major or minor strike-bends, or strike-corrugations, with steeply pitching axes (1934, 1937).

In spite of these complications he has claimed from field observation that (1) the Ballappel Foundation (which includes, besides Dalradian, Eilde Flags commonly correlated with Moinian) passes south-eastwards and south-westwards under the Dalradian of the Iltay Nappe along the line of a Boundary Slide extending from the neighbourhood of Ben Doirean to near Loch Creran, and that (2) the Moinian in the Schichallion area passes south-eastwards under the Dalradian of the Iltay Nappe along the line of a slide that has locally been subjected to subsequent recumbent folding and twisting.

It will be noticed that, on Pl. V, the Loch Skerrols Thrust in Islay is labelled 'Iltay Boundary Slide.' This is a logical consequence of Kennedy's allocation of the Great Glen Fault to a position north-west of Colonsay, combined with Bailey's general interpretation of the Iltay Nappe-complex. An attempt has been made to express this interpretation in the diagrammatic section on Pl. V, which has been submitted to Bailey and accepted by him (cf. Fig. 6). Bailey is not now inclined to adopt Kennedy's identification of the Loch Skerrols Thrust with the Moine Thrust (Fig. 3)[2] which he himself had once tentatively suggested on other grounds (1917, p. 139).

Bailey, by introducing slides, has offered a solution of the problem presented by what are known in the Dalradian Highlands as the *three-sided* formations; that is, a rock-group that is in contact with other rock-groups besides the two between which it falls in the natural stratigraphical sequence. For instance, in the Ballachulish area, the Appin Quartzite is considered to have, in normal stratigraphical order, on one side the Appin Phyllites and on the other Ballachulish Slates; these are the two natural sides of the quartzite. But on the south side of Loch Leven, the Appin Quartzite is found in contact with Leven Schists : it is thus a three-sided formation requiring an explanation. Bailey supplies this by the existence of the Ballachulish Slide at the unnatural junction of Appin Quartzite and Leven Schists.

According to J. F. N. Green, a non-believer in recumbent folding and sliding, the three-sidedness of a formation may arise by an unconformity of a special type. Above the unconformity (marked locally by the Portaskaig Conglomerate) the basal beds consist of various members, any or all of which may taper out. This, of course, is admittedly possible, but in the writers' opinion is not adequate to explain the Ballachulish phenomena.

[1] 'Secondary' as used here does not necessarily imply two periods of folding.

[2] Personal communication. Bailey quite recently welcomed this identification (Kennedy, 1946, p. 63, and discussion p. 73). A.G.M.

Whilst Bailey has been the main exponent of the nappe hypothesis in the Dalradian Highlands, several later workers have in part confirmed, extended or modified his views. H. H. Read has suggested the possibility of explaining the asymmetry of the Banff syncline in north-east Scotland by the existence of a Banff nappe. In the Schichallion district, E. M. Anderson suggested a 'folded rupture' between the Dalradian and Moine rocks. W. J. McCallien has continued the Cowal structures across Kintyre. G. L. Elles has described the Ben Lawers Slide, with the Ben Lawers Nappe lying above it. For the South-west Highlands, G. L. Elles and C. E. Tilley, in 1930, regarded the fundamental folding as large-scale recumbent folding, which has affected not only the stratigraphical divisions, but also the metamorphic. Since the high-grade cores were then thought to close towards the south-east, the impulse was considered to have come from the north-west. Secondary folding was admitted; this movement had no constructive metamorphism and culminated in a series of thrusts with an overdrive to the north-west. These authors consider Bailey's thrust at the base of his Loch Awe Nappe as not necessary to explain the structure (p. 23).

(3) The third type of interpretation of the Dalradian tectonics was bequeathed by B. N. Peach in a few sections across the country. These have the following main features (Fig. 6). The entire Highlands are made up of Lewisian, Torridonian, Cambrian and Ordovician. Their structures result from the approach of two rigid areas, one from the north-north-west, the other from the south-south-east. At the margins of these rigid areas thrusting occurred, giving the Moine Thrust, etc., and the Highland Boundary Fault. Farther from the margins recumbent folding took place, whilst in the central region of greatest load, a great fan structure was produced. This interpretation depends, first, upon Peach's view that the Moine Series and Torridonian are equivalent, and that the schist-making period in the Highlands is post-Cambrian, and, secondly, upon the following detailed correlations: (*a*) Erins or Loch Fyne Quartzite=the Pebbly (Q4) Quartzite of Islay; (*b*) Tayvallich or Keills Lavas of Loch Awe=Serpentine of Glendaruel=Lavas of Highland Border Series; (*c*) Loch Tay Limestone=Margie Limestone; (*d*) Dunoon Phyllites=Pitlochry Schists. Others now claim that (1) some or all of the Dalradian is Cambrian ; (2) Dalradian metamorphism is thus of Caledonian age (e.g., Holtedahl, 1939 ; Anderson, 1947).

(*e*) COMPARISONS WITH IRELAND, NORWAY, AND THE ALPS

Correlations of parts of the Perthshire, Islay, and Loch Awe successions with Irish rocks in Antrim and Donegal have been put forward by W. J. McCallien (1931, 1934, 1935, 1937). It was McCallien's Inishowen (Donegal) evidence that led Bailey to abandon his conception of a thrust below his Loch Awe Nappe (Allison, 1940: discussion). Analogies between the succession and tectonics in the metamorphic rocks of Scotland and Norway have been suggested by E. B. Bailey and O. Holtedahl (1938, 1939). Dalradian and Alpine tectonics and metamorphism have been compared by F. E. Suess (1931).

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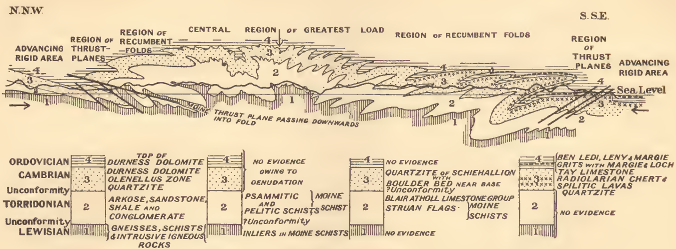

FIG. 6.—*Diagrammatic Section across the entire Highlands, drawn by B. N. Peach.*

(Reproduced from 'Chapters on the Geology of Scotland,' by B. N. Peach and J. Horne, by kind permission of the Oxford University Press.)

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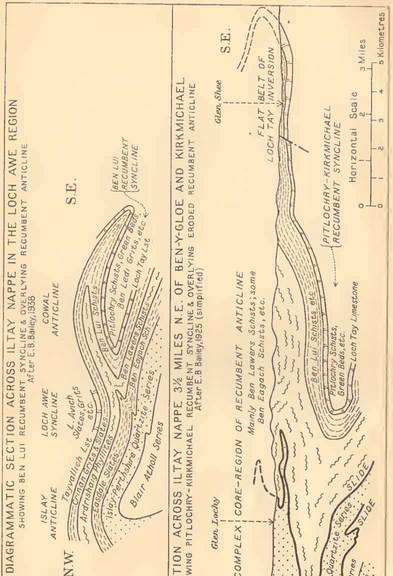

FIG. 7.—*Sections illustrating Recumbent Fold Structures in the Southern Highlands, after Sir E. B. Bailey.*

V. IGNEOUS ROCKS EARLIER THAN, OR ASSOCIATED WITH, THE DALRADIAN METAMORPHISM

1. CONTEMPORANEOUS IGNEOUS ROCKS IN THE DALRADIAN SERIES

UNDOUBTED PILLOW-LAVAS were discovered by B. N. Peach in 1903 at Tayvallich in the Loch Awe district, being part of a great group of rocks of this region that, up to this time, had been regarded as intrusions of a special type. These lavas are typical pillow-lavas of spilitic affinities, as shown by chemical analyses. By all except G. L. Elles they are said to present a bottom portion with pipe-amygdales, a central pillowy portion and a top vesicular portion, which can be used in determining the age-relations of the associated sediments. Tuffs and agglomerates are rare, but conglomerates containing lava fragments are common. Certain feldspathic beds in the Tayvallich peninsula are interpreted as crystal-tuffs.

In the River Blackwater, near Ardwell Inn, some ten miles south-west of Huntly (Sheet 85), igneous rocks, probably basic lavas, have been described by W. Mackie. The position of these beds in the Highland sequence is not yet known.

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2. INTRUSIONS ('OLDER IGNEOUS ROCKS') IN THE MOINE AND DALRADIAN SERIES

These rocks may be subdivided into two groups: (*a*) Greenstones, (*b*) Older Granites.

(*a*) GREENSTONES

Basic older igneous rocks are well developed in the Dalradian Series. They form sills or sheets often extending along the strike for great distances. Now almost everywhere composed of amphibolite, epidiorite or hornblende-schist, they exhibit their original character in certain favoured localities, as at Portsoy in Banffshire, where the parent rock of the thicker sills is seen to be gabbro, with rarer enstatite-gabbro. The main horizon for greenstone sills is between the Loch Tay Limestone and the Central Highland Quartzite. A great sill, or sills, in this position stretches from Portsoy southwards for fifty miles to Deeside. At various points along this sill—Portsoy, Upper Deveron, Strath Don, Coyles of Muick—large bodies of ultrabasic rock, now serpentine and associated types, accompany the greenstones. At Portsoy, also, the corresponding feldspathic pole is represented by a small body of anorthosite. Elsewhere in the Dalradian area thin sills are closely associated with the Loch Tay Limestone and, in Cowal, small bodies of serpentine are found. This Greenstone Horizon has been employed by H. H. Read in certain correlations of the Deeside schists (*see ante*, p. 19). The great greenstone laccolith on Ben Vrackie (Sheet 55) in the Ben Lawers Group of sedimentary schists has produced hornfelses in the adjacent rocks which have thus been able to resist later deformation-movements (pre-folding hornfelses).

Associated with the lavas of the Loch Awe district are innumerable greenstone intrusions not all markedly spilitic in affinities; with these occur rare soda-felsite, keratophyre and soda-granite-porphyry.

The progressive metamorphism of the epidiorites of the Central and South-west Highlands has been studied by J. D. H. Wiseman.

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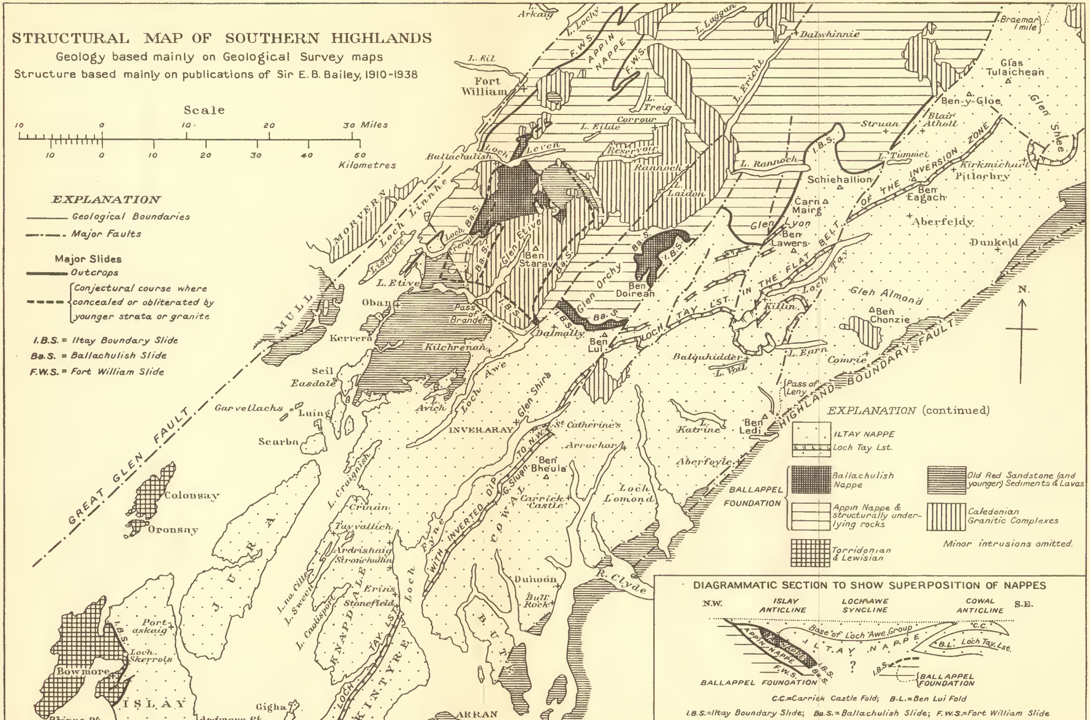
(*b*) OLDER GRANITES

This great group of intrusions includes all those acid rocks intruded prior to, during or immediately after the production of the regional metamorphism of the Dalradian rocks. They belong to what H. H. Read has called the Movement Phase. Certain of the rocks of this group had consolidated before the movements responsible for the foliation of the schistose rocks; these are now represented by augen-granites, such as those of Portsoy, Keith and the Ben Vuroch area. The main portion of the Older Granite, however, is believed to be intimately connected with the mountain-building period. Large bodies of Older Granite are uncommon, the typical mode of occurrence of these rocks being in small sills, threads and veins permeating the country-rocks. G. Barrow, who has studied the Older Granites in detail (Fig. 8), regards them as responsible for the high grade of metamorphism of the associated country-rocks, the zone of sillimanite being located where the Older Granite is present in abundance and the other metamorphic zones being arranged around this focus of magmatic activity. As the various intrusive masses are followed towards the south-east, the amount of muscovite and microcline increases, and of biotite and plagioclase decreases, a phenomenon explained by Barrow as due to the straining-off of potash-rich material towards the south-east. The complex of the Older Granites thus resulted from the progressive squeezing-out of the liquid portion of a granitic



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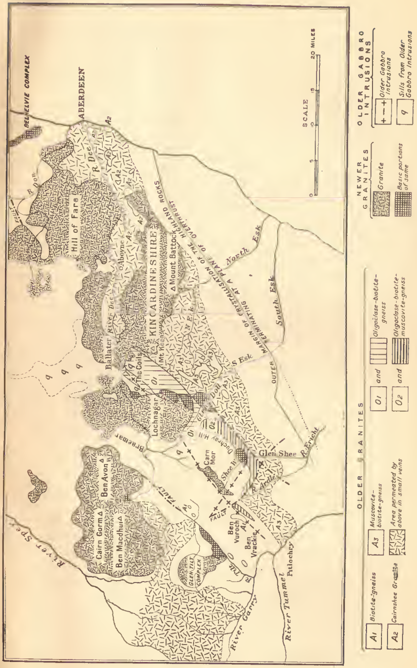

FIG. 8.—*Relations of the Older and Newer Granite of the Central Highlands, after G. Barrow.*

magma consolidating under stress. Barrow has given the following classification of the chief types of Older Granite:—

Alkali-granite Type	Granodiorite Type
A1. *Brown mica only present* Biotite-gneiss of Ben Vuroch, Glen Tilt, etc.	O1. *Oligoclase-biotite-gneiss* Glen Muick, Glen Doll
A2. *Biotite exceeds muscovite* Cairnshee Granite. Dyke veins in west	O2. *Oligoclase - biotite - muscovite - gneiss* Duchray Hill Gneiss
A3. *Muscovite exceeds biotite* Muscovite-biotite-granite and gneiss of Forfar. Pegmatite veins specially abundant	O3. *Oligoclase-muscovite-gneiss* Present only in small amount in veins

Certain of Barrow's types, *e.g.*, oligoclase-biotite-gneiss, are considered by H. H. Read (1927) to result from the admixture, both chemical and mechanical, of a trondhjemitic oligoclase-rich magma and dominantly pelitic sediments. Similarly, the Duchray Hill Gneiss (oligoclase-muscovite-biotite-gneiss), according to W. O. Williamson (1935), was formed by quartz-oligoclase magma invading the pelitic portion of the Ben Lui Schists. H. H. Read had previously directed attention to the horizon of injection of the Older Granite magma between the Central Highland Quartzite and Loch Tay Limestone (*cf.* p. 40), and had used this factor in his correlation of the Deeside rocks with those farther south (*see ante*, p. 19).

D. L. Reynolds (1942) regards Barrow's 'older granites' as migmatite, representing an igneous phase contemporaneous with Caledonian orogenys and discusses this syntectonic igneous phase, with its Na—Ca—Si and K—Fe—Mg—Al 'fronts,' in relation to maps showing Scottish Caledonian structures and regional metamorphic zones. She regards the development of schists and gneisses with porphyroblastic albite or oligoclase, as produced from non-albitic pelites by the migration of chemical elements through the framework of a moving recumbent anticline, *e.g.*, the Carrick Castle Fold. Sodium is regarded as the only important migratory element that need be envisaged as coming from a deep-seated external source.

A large separate intrusion of Older Granite in the Ben Vuroch Area, six miles north-north-east of Pitlochry, has been investigated by G. Barrow. It has been profoundly affected by earth-movements resulting in the production of augen-gneisses. This movement came from the east-south-east, and on this side the intrusion has been sheared to a schist, while on the opposite side the rock has largely escaped shearing. Similarly, the country-rocks on the south and east sides of the granite have been greatly affected by the schistosity movement, whilst those on the other sides have been protected. These protected rocks show the hornfels or contact type of alteration; this is not due, in Barrow's opinion, to contact-action by the adjacent granite, but is part of the general Highland metamorphism. Barrow's views on this subject are as follows:—

(i) The hornfels type of alteration is confined to areas flooded by oligoclase-biotite-gneiss, the oldest of the Older Granite magma, anterior to crush-movements and strain-slip.

(ii) This early induration is broken down by later crush-movements leading to lenticular structure.

(iii) Later intrusions of Older Granite magma raised the whole area to a very high temperature. The crystallization now seen, except where protected as at Ben Vuroch, is of the age of this maximum temperature.

These conclusions appear to be invalidated by the observations of A. G. MacGregor and W. O. Williamson on the Glen Doll—Duchray Hill Gneisses (schists, etc., injected by Older Granite) in the contact-aureoles of the Newer ' diorites ' of Glen Doll and Glen Shee (*see* Fig. 8, and p. 50).

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VI. CAMBRO-ORDOVICIAN: HIGHLAND BORDER SERIES

DISCONNECTED NARROW WEDGES of rocks which, from their fossil contents, have been referred to the Cambro-Ordovician appear at intervals along the Highland Boundary Fault (Fig. 9). These wedges are usually

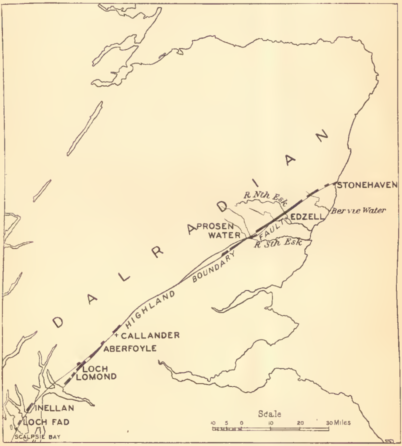

FIG. 9.—*The Distribution of the Highland Border Series.*

bounded by steep thrusts or faults (Pl. VIA), but at Stonehaven Cambro-Ordovician rocks are followed towards the south-east by unconformable Downtonian strata. In addition to sediments, this group, best known as the Highland Border Series, includes lavas and a series of plutonic rocks, both of which are described here.

The Highland Border Series can be separated into two groups:

(i) a *Lower* or *Black Shale and Chert Series* with spilitic lavas and basic and ultrabasic intrusives.

(ii) an *Upper* or *Margie Series*, separated from the lower by a marked unconformity.

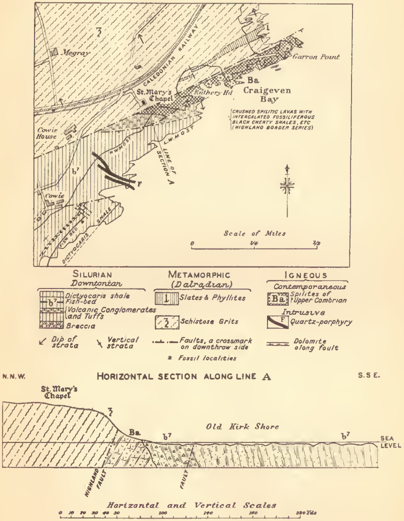

FIG. 10.—*Geological Map of the Stonehaven District.*

A representative section is seen in the North Esk and has been described by G. Barrow:

(i) the *Lower Series*—Jasper and Green Rock Series, consisting of: (1) green rocks, mainly lenticular sills of ophitic dolerite, though some lava flows may be present; (2) Jasper and jaspery phyllite, 6 ft.; (3) cleaved fine shale; (4) fine grit with microcline pebbles.

(ii) The *Upper* or *Margie Series*, consisting of: (1) local green conglomerate with jasper pebbles, 30 ft.; (2) pebbly ferruginous grits, 120 ft.; (3) dark grey, brown and white shales, 20 ft.; (4) pebbly Margie Limestone, 1–5 ft.; and (5) grey shale.

The Lower Series is well seen at Stonehaven (Fig. 10) and at Aberfoyle where it yielded fossils to R. Campbell and T. J. Jehu. It consists of spilitic lavas, with cherts, jaspers and black shales. The important members of the Margie Series are the Basal Conglomerate, and the Margie Limestone; the latter is well seen at Margie, Upper Dounans (Aberfoyle) and Kilmahog (Callander). It will be recalled that Peach, in his diagrammatic section across Scotland (1930, Pl. xviii), correlated the Margie and Loch Tay Limestones (p. 34). At Upper Dounans there have been found crinoid plates, calcareous algae and probably foraminifera. From its relations to the Lower Series, the Margie Series was, until recently, presumed to be Ordovician. J. Pringle has, however, recorded Middle Cambrian trilobites and brachiopods in limestones of the Callander district long regarded as the equivalents of the Margie Limestone. He has also found a shear zone separating the supposed basal Margie conglomerate from the adjacent Margie Grits. He suggests: (1) the Margie Series is therefore Cambrian, and thus older than Barrow's Jasper and Green Rock Series; (2) the local green conglomerate with jasper pebbles, supposed by Barrow to be the basal part of the Margie Series, belongs in reality to the Jasper and Green Rock Series; (3) the Jasper and Green Rock Series lies in a folded trough and not in a compound anticline as previously supposed.

Associated with these sedimentary and volcanic rocks is a group of intrusives, basic and ultrabasic, represented by diabases, gabbros and serpentines, and their sheared derivatives, hornblendic and chloritic schists. Often the serpentine is represented by a thick dolomite belt. Patches of this serpentine appear at Scalpsie Bay and Loch Fad in Bute, Inellan and Toward Point on the Firth of Clyde, at Balmaha, Aberfoyle, Glen Isla, Prosen Water and elsewhere.

Fossils of the Highland Border Series

Stonehaven.—*Lingulella, Obolella, Acrotreta, Linnarssonia, Siphonotreta;* bivalve phyllocarid; tubicolar worm.

Aberfoyle.—*Radiolaria.*

Graptolitoidea.

Brachiopoda: Obolus, Lingulella aff. *ferruginea* Salter, *L.* aff. *nicholsoni* Callaway, *Acrothele* (*Obolella*) *maculata* Salter, *A.* (*Redlichella*) *granulata* (Linn.), *A.* aff. *coriaceae* (Linn.), *Acrotreta nicholsoni* Dav., *A. socialis* von Seebach, *A.* aff. *sabrinae* Callaway, *Siphonotreta* aff. *micula* M'Coy, *S.* aff. *scotica* Dav., ? *Schizambon.*

Phyllocarida: Modiolocaris dakynsi Peach.

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[1] Anderson regards the Margie (= Leny–Kilmahog and Rothesay) Limestone as intercalated between the Leny (= Ben Ledi) Grits and certain younger grits represented at Rothesay (Bute) and North Sannox (Arran). Stratigraphically above these Dalradian (= Cambrian) rocks come Ordovician strata: Arenig spilitic lavas, black shales and cherts (including the Jasper and Green Rock Series) and post-Arenig (? Caradoc) beds which includes a local part of the so-called Margie Series, and the Dounans (= Aberfoyle) Limestone. He thus regards outcrops of Highland Border limestones, formerly correlated as 'Margie Limestones,' as representing two distinct limestone horizons, one Dalradian (= Cambrian) and one Ordovician.

VII. INTRUSIVE IGNEOUS ROCKS POSSIBLY OF LATE SILURIAN AGE

IGNEOUS ROCKS, BOTH plutonic and hypabyssal, later than the regional metamorphism of the Highland Schists, but earlier than the Middle Old Red Sandstone, are very extensively developed in the Grampian Highlands. Certain of these intrusions cut Lower Old Red Sandstone rocks, and are taken as the plutonic and hypabyssal representatives of Lower Old Red Sandstone igneous activity; these intrusions and allied rocks which, in the

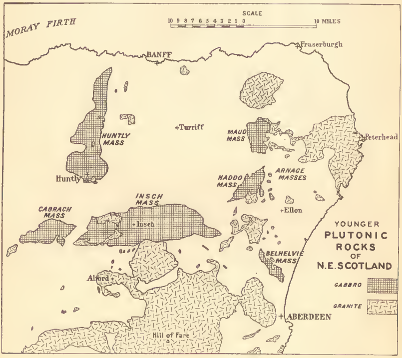

FIG. 11.—*The Younger or Newer Plutonic Rocks of North-east Scotland.*

Grampian Highlands area, occur mainly in Argyllshire, are dealt with in Chapter VIII of this account. Other great intrusions, especially well developed in Aberdeenshire and adjacent regions, are like those that contributed abundant material to the conglomerates of the Downtonian and Lower Old Red Sandstone. This group is believed by many to be in part of late Silurian age but, like the Lower Old Red Sandstone intrusions, to be related to the Caledonian epoch of folding. The terms *Caledonian Intrusions, Newer Granites* and *Younger Granites* have all been used to cover the whole of the intrusive rocks dealt with in Chapters VII and VIII.

The so-called *Late Silurian Newer Granite Intrusions* range from ultrabasic to acid in composition. Two great groups may be separated which are

(*C.*2159)

A. West Bank of River North Esk, Doulie, Edzell
[For explanation, *see* p. viii]

(*C.*2638)

B.—Rudh a' Bhearnaig, Kerrera, Oban
[For explanation, *see* p. viii]

(*B*.619)

A.—Coire nam Beitheach, Glen Coe
[For full explanation, *see* p. viii]

(*C*.1474)

B.—Shore at Covesea, $3\frac{3}{4}$ miles west of Lossiemouth
[For explanation, *see* p. viii]

(*C*.1244)

A.—Mouth of the Allt Bun an Eas, south of Loch Tarbert, west coast of Jura
[For explanation, *see* p. viii]

(*B*.725)

B.—North Coast of Islay
[For explanation, *see* p. viii]

probably distinct. These are: (1) Gabbros of North-east Scotland; (2) Granites of the Central Highlands, Newer Granites proper.

1. GABBROS OF NORTH-EAST SCOTLAND

In the Buchan and Strathbogie districts of Aberdeenshire and Banffshire there are half a dozen great sill-like masses of gabbroic rocks (*see* Fig. 11). These are of considerable size, the Insch Mass exceeding seventy square miles, the Huntly Mass fifty. The latter mass consists of sheet-intrusions of peridotite, olivine-gabbro, troctolite, and noritic gabbros and small granite bosses. The Insch Mass comprises peridotite, troctolite, olivine-norite, hypersthene-gabbro, quartz-diorite, syenite and granite. Other bodies show similar ultrabasic and basic types. The basic rocks are intruded by the more acid types. There is therefore in North-east Scotland a great petrographic province characterized by the development on a large scale of true calc-alkaline gabbroic rocks.

In many localities the original gabbro magma has reacted with sedimentary country-rocks of argillaceous composition to produce norites containing cordierite, garnet and other minerals not normal in pure igneous rocks. Such *contaminated igneous rocks* are crowded with innumerable small xenoliths of country-rock and their origin by assimilation of sedimentary material is beyond question. Good localities for studying such xenolithic complexes are at Cuternach at the western edge of the Huntly Mass and in the River Deveron below Castle Bridge at Huntly, at Easter Saphook at the east end of the Insch Mass, and especially at Wood of Schivas in the Haddo Mass.

Magnificent aureoles of thermal metamorphism are produced in the adjacent Highland Schists by many of these basic masses. The best example is seen at the northern margin of the Insch Mass, near Wishach Hill and Hill of Foudland. Here the upper surface of the gabbro is sloping gently to the north under a roof of slates belonging to the Macduff Group of the Highland Schists. In consequence, the breadth of the aureole of thermally-altered rocks is unusually great, being over a mile in some places. The unaltered slates are well-cleaved rocks, the cleavage coinciding with the bedding in most cases. The first evidence of contact-alteration is shown by the development of small rounded spots of andalusite and cordierite in the slaty groundmass; at the same time the rocks lose their cleavage and become massive. Farther in towards the igneous contact, the spotted rocks pass into totally reconstructed andalusite-cordierite-hornfelses of the inner zone of thermal alteration.

2. GRANITES

This group is represented by the great granite masses of Cairngorm, Lochnagar, Hill of Fare and Kincardineshire (Fig. 8), together with numerous smaller bodies, such as those of Bennachie, Peterhead, Strichen, Ben Rhinnes, Monadhliadh, etc. (Fig. 12). The form of some of these granite masses, for example, the Cairngorm mass, is thought to be that of a laccolith or sheet; the existence of a flattish top to this mass is generally agreed upon, whilst the presence of a base has been suggested at certain localities. In some other cases, such as that of the Lochnagar Mass, the shape of the outcrop appears to indicate that the granite may possess some kind of annular or ring form similar to that presented by the Etive granite-complex described later at p. 54.

W. Q. Kennedy regards the Foyers granite-complex as being the southern portion of the Morvern—Strontian granite-complex displaced sixty-five miles north-eastwards (Fig. 3) by the Great Glen Fault (Kennedy, 1946, Figs. 5 and 6; *see also* Mould, 1946).

The chief rock-type is biotite-granite with little or no muscovite or microcline, but these minerals become important in the Nairnshire granites (Moy, Ardclach), in some Banffshire examples (Strathbogie) and in the granites of Kemnay and Coull near Aberdeen. Associated with the large granite masses are small bodies of more basic character, consisting of hornblende-granites, tonalites and diorites; certain of these types are similar to members of the appinite suite of the South-west Highlands (*see* p. 55).

FIG. 12.—*The Newer Granites of North-east Scotland.*

Some masses are of complex structure, such as those of Comrie (mostly diorite: Fig. 16), of Glen Doll (serpentine, picrite, basic diorite and diorite: Fig. 8), of Glen Tilt (augite-diorite, tonalite, hornblende-granite, biotite-granite, muscovite-granite, aplite: Fig. 8) and of Netherly, Dandaleith, etc. These basic intrusions are slightly earlier than the acid.

The hypabyssal phase is represented by a series of dykes, sills and small masses of calc-alkalic facies. Common types are: aplite, pegmatite, felsite, quartz-porphyry, feldspar-porphyry, microgranite, quartz-felsite, porphyrites with hornblende and biotite, vogesites, minettes, kersantites and spessartites, and peridotites. These are similar to the minor intrusions of Lower Old Red Sandstone age described below. The relations between the various members of the hypabyssal phase are varied: in some districts lamprophyres cut porphyrites, in others the reverse takes place. There are probably many series, some aschistic such as the porphyrites, others diaschistic such as the lamprophyre-aplite group. Some of these rocks are affected by shearing, producing, for example, lampro-schists.

Thermal alteration due to the Newer Granites has been described from many localities. According to A. G. MacGregor and W. O. Williamson cordierite-sillimanite-andalusite-corundum-spinel hornfelses have been formed from Glen Doll and Duchray Hill Gneiss (contaminated Older Granite) by contact-metamorphism due to Newer diorite and granodiorite. In hornfelsed pelitic schist, close to the margin of the Lochnagar granite, A. G. MacGregor has found cordierite, large andalusites, and sheafy andalusite replacing large (pre-Newer Granite) kyanite porphyroblasts. The most detailed study is that by A. G. Hutchison, and is concerned with the changes undergone by the Deeside Limestone in proximity to the granites of Black Craig and Pannanich Hill in the valley of the Pollagach Burn near Dinnet in Middle Deeside. In its regional development the Deeside Limestone is a diopside-plagioclase-limestone with the following assemblage: calcite, quartz, orthoclase, microcline, plagioclases from albite to anorthite, scapolite, clinozoisite-epidote, diopside, amphiboles, biotite and grossular (in one case). The outer part of the thermal aureole due to the Newer Granites is characterized by the development of granular diopside from the amphibole of the regional limestone; the inner part by high-grade hornfelses with such minerals as plagioclase, grossular, diopside, wollastonite and vesuvianite. Many of these hornfelses have suffered pneumatolytic and hydrothermal alteration with the production of scapolite, prehnite, apophyllite and analcite.

A detailed study by C. E. Tilley of the aureole around the Comrie diorite deals with the production of many kinds of sedimentary hornfelses, both those rich in silica and those poor in silica. The free-silica group is characterized by the occurrence of andalusite, cordierite, hypersthene, diopside, plagioclase and biotite; the silica-poor group shows corundum and spinel.

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VIII. INTRUSIVE IGNEOUS ROCKS MAINLY OF LOWER OLD RED SANDSTONE AGE

INTRUSIONS SHOWN TO be in part later than Lower Old Red Sandstone rocks are very well developed in the South-west Highlands (Figs. 13, 16).

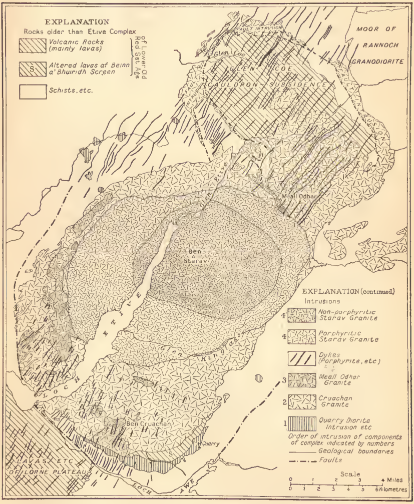

FIG. 13.—*The Etive Complex and its Relation to the Glen Coe Cauldron-subsidence, partly after J. G. C. Anderson*, 1937.

Plutonic examples of this group are the great granites of Cruachan, Ben Nevis, etc., whilst the hypabyssal phase is represented abundantly by sills and dykes from Perthshire south-westwards.

1. PLUTONIC

The greatest plutonic intrusion is that of the Glen Etive Complex (Fig. 13). According to the views of C. T. Clough, H. B. Maufe and E. B. Bailey (Memoir, 'Ben Nevis and Glen Coe,' 1916), as modified in detail by J. G. C. Anderson (1937), it consists of a ring-complex of four, or possibly five, successive granitic intrusions emplaced as the result of four (or five) successive cauldron-subsidences. During each period of cauldron formation

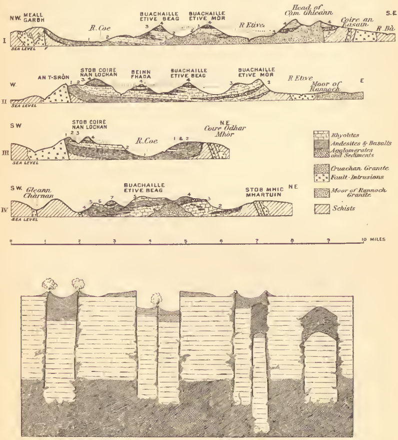

FIG. 14.—*Sections across Glen Coe, and the Suggested Mechanism of Cauldron-subsidence.*

a somewhat cylindrical block is supposed to have subsided within a ring fracture, while granitic magma rose along the fracture-zone and occupied the space above (Fig. 14: lower portion[1]). A remarkable feature of tas southern margin of the complex is the presence of a 'screen' of lavas between the Quarry-diorite and the Cruachan granite. The lavas have been

[1] This diagram was first published in 1909. According to more modern ideas, the diameters of the ring-fracture and 'cylindrical' block increase in depth (J. E. Richey, 'Tertiary Ring-Structures in Britain,' *Trans. Geol. Soc. Glasgow*, vol. xix, pt. i, 1932, pp. 116–139).

thermally metamorphosed, and locally changed into schists by shearing stress due to cauldron-subsidence.

The Cruachan Granite has an advance guard to the north in the Fault-Intrusion (ring-dyke) of Glen Coe (Pl. VIIA), which in some places passes into Cruachan Granite and in others is cut by it. This intrusion welled up as a block of Lower Old Red Sandstone lavas and Highland Schists subsided; it consists of porphyrite merging into granite (*see* p. 60 and Figs. 14, 16 and 17). Ben Nevis provides evidence of a somewhat similar cauldron mechanism (*see* p. 60 and Fig. 18), there being three interrupted arcuate marginal quartz-diorite intrusions, an outer granite and an inner later, more acid granite (Maufe, 1910; Anderson, 1935). The times of intrusion of the inner and outer granites were separated by an epoch of great hypabyssal activity. The rocks of the usual granitic intrusions are of calc-alkaline facies and comprise such monzonitic or granodioritic types as aplogranite, granitite, tonalite, banatite, adamellite, aplodiorite, granodiorite and calc-tonalite. With these more acid types are associated innumerable small bosses of more basic rocks, appinite, augite-diorite, monzonite, kentallenite and cortlandtite. Other granite masses reckoned with those of Lower Old Red Sandstone age are the Mullach nan Coirean and Meall a'Chaoruinn granites and the Ballachulish granite. The latter intrusion is in places full of sedimentary xenoliths.

The great granodiorite mass of the Moor of Rannoch is also considered by many as of Lower Old Red Sandstone age but to belong to an early phase of this period of igneous activity, since it is cut by the Fault-Intrusion of Glen Coe. It has a marginal part consisting of biotite-granite and a central part of hornblende-biotite-granitite or granodiorite. At its margins the granite forms an intricate intrusion-complex with the surrounding country-rocks.

Some recently studied intrusive complexes near the head of Loch Lomond are most conveniently considered here, though they may possibly be of late Silurian age; they are those of Garabal Hill—Glen Fyne (peridotite, pyroxenite, hornblendite, gabbro, pyroxene-mica-diorite, appinite, quartz-diorite, granodiorite, aplite, and pegmatite), of Arrochar (pyroxenite, kentallenite, appinite, pyroxene-mica-diorite, hornblende-diorite, quartz-diorite, biotite-granite), and of Glen Falloch (picrite, kentallenite, pyroxene-diorite, appinite, hornblende-diorite). S. R. Nockolds (1941), following up earlier work by J. R. Dakyns, J. J. H. Teall, B. K. N. Wyllie and A. Scott, has made a very detailed study of the Garabal Hill—Glen Fyne complex (Fig. 18), and explains its history in terms of crystallization-differentiation accompanied by some contamination. In the Garabal Hill and Arrochar complexes the most acid rocks are the youngest, and the order of intrusion is broadly from basic to acid, though not strictly in the order of rock types as set out above.

2. HYPABYSSAL

Dykes and sills of igneous rocks connected with the Lower Old Red Sandstone activity are exceedingly abundant in the South-west Highlands, where the dykes form north-north-east to south-south-west 'swarms.' Before the description of these is given, however, two minor groups of earlier date have to be mentioned. These are (1) certain early lamprophyre

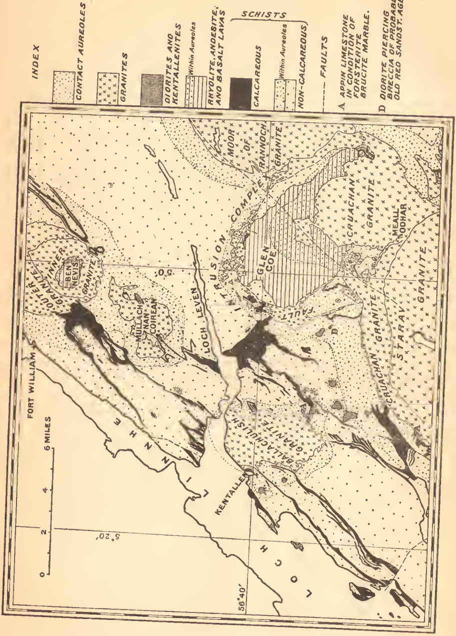

Fig. 15.—*The Aureoles of Thermal Metamorphism around the Ballachulish Granites.*

(spessartite and vogesite) sheets which are cut by the north-north-east dykes and are probably earlier than the Moor of Rannoch granodiorite, and (2) early felsitic and andesitic intrusions of Glen Coe which were probably contemporaneous with the volcanic episode of the district; this astl group consists of quartz-porphyry, felsite and hornblende-andesite.

The great series of north-north-east to south-south-west dykes is the main manifestation of Lower Old Red Sandstone hypabyssal activity. The dykes were intruded during a period of tension after the intrusion of the first or outer granites of the cauldron-subsidences; few or none cut the later or inner granites (Figs. 13, 18). Intrusions of this phase occur in vast numbers —it is estimated that of the long diameter of nine miles of the Glen Coe Cauldron-subsidence, the elongation due to dykes amounts to two and a half miles. There are two main swarms or clusters of dykes, the Etive Swarm associated with the Etive Complex, and a lesser swarm at Ben Nevis. The petrographic types include felsites, quartz-porphyrites, biotite-porphyrites, hornblende-porphyrites, spessartites and olivine-kersantites. The order of intrusion of the different types of hypabyssal rocks is not uniform.

Around the plutonic intrusions the country-rocks have suffered thorough contact-metamorphism, with the development of calc-silicate-hornfelses, and of argillaceous hornfelses with sillimanite, cordierite, corundum, spinel and andalusite (Fig. 15). The destruction of muscovite, chlorite, garnet and quartz, and the building-up of feldspar, andalusite and cordierite are well seen in these argillaceous hornfelses. Andesite lavas and porphyrite dykes on contact-metamorphism pass into granulitic rocks, brown hornblende and other ferromagnesian minerals giving place to small biotite flakes with aggregates of green hornblende and iron-ores. Lime-soda feldspar phenocrysts have acquired a peculiar cloudiness, due to minute inclusions (MacGregor, 1931).

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IX. OLD RED SANDSTONE

THE OLD RED Sandstone formation of the region described here is divisible into three portions, Lower, Middle and Upper, each characterized by a particular fish fauna. The Lower division alone occurs south of the Grampians, whilst the Middle and Upper divisions, separated by an unconformity, represent the formation to the north of these mountains.

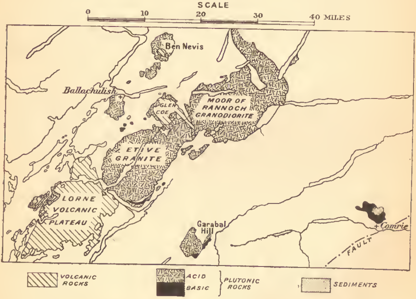

FIG. 16.—*Sedimentary Rocks of Lower Old Red Sandstone Age, and Caledonian and Lower Old Red Sandstone Igneous Rocks of the South-west Highlands.*

1. LOWER OLD RED SANDSTONE LAVAS AND SEDIMENTS

Rocks beonging to the lower division of the Old Red Sandstone form the Lorne Plateau between Loch Awe and Oban, and, in addition, appear in smaller areas in Glen Coe and Ben Nevis (Fig. 16). The rocks are chiefly lavas.

Lorne Plateau.—The rock-types of the Lower Old Red Sandstone of this district are lavas—basic andesites, hypersthene- and biotite-andesites, and felsitic lavas—agglomerates, tuffs, ashes, ashy grits, breccias, conglomerates, sandstones, grits, flags, shales and thin limestones. These materials rest with a marked unconformity on the underlying Highland

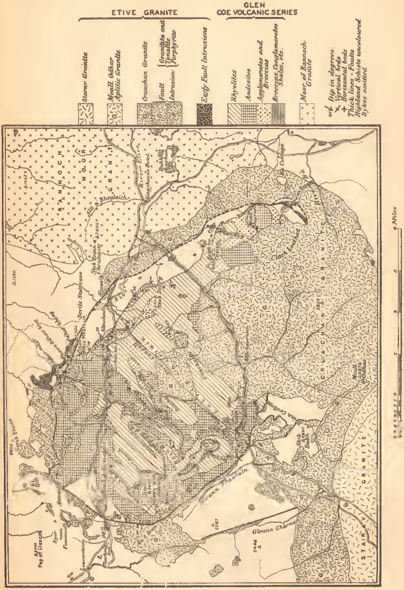

Fig. 17.—*The Cauldron-subsidence of Glen Coe, after C. T. Clough, H. B. Maufe, and E. B. Bailey.*

Schists (Pl. VIb). The sediments are best developed in the Oban and Kerrera districts, whence they thin out towards the east. The volcanic pile dips generally east-south-east to south-south-east, and gradually thins in an easterly direction also. The thickness of the volcanic pile exceeds 2,000 ft., whilst the local basal conglomerate varies from 100 to 200 ft. The general succession in Lorne is:—

(1) Base: local breccias and conglomerates with shales and sandstones.

(2) Basic andesites with occasional flows of hypersthene-andesite.

(3) Acid tuffs and basic flows.

(4) Tuffs, felsitic flows, and hornblende- and mica-andesites.

(5) Hypersthene-andesites, with intercalations of basic andesite and andesitic agglomerate.

Fossils from the Oban districts include the following:—

Fish: *Cephalaspis lornensis* Traq., *Mesacanthus mitchelli* Eg., *Thelodus sp.*
Euryterid: *Pterygotus anglicus* Ag.

Millipedes: *Kampecaris forfarensis* Page, *K. obanensis* Peach.

Ostracods: *Aparchites sp.*, *Isochilina sp.*, *Beyrichia* (?) *sp.* or *Drepanella sp.*
Plants: Forms compared with *Psilophyton* and *Pachytheca.*

Glen Coe.—In Glen Coe (Fig. 17) rocks of Lower Old Red Sandstone age occupy a cauldron-subsidence surrounded by an arcuate fault of some thousands of feet downthrow, against which the 'fault-intrusion' is chilled (*see ante*, p. 55). The rocks approach 4,000 ft. in thickness and consist almost entirely of basic andesites, hornblende-andesites and rhyolites, with quite subordinate breccias, conglomerates, sandstones, shales and grits. Erosion has revealed the fact that, within the ring-fracture, this series rests with a violent unconformity on Highland Schists, its basal member being a breccia.

Ben Nevis—The summit of Ben Nevis is formed by a core of volcanic rocks 2,000 ft. in thickness (Fig. 18). These can locally be seen to rest unconformably on Highland Schists, the succession being basement conglomerate 8 ft. thick, followed by 40 ft. black shale, and then agglomerates and lavas up to 2,000 ft., with a couple of bands of dark shale. According to Maufe, the last stage of cauldron-subsidence at Ben Nevis was an event that did not occur at Etive or Glen Coe; namely a local collapse of a cauldron roof, consisting of a block of schists with its burden of lavas. The mass sank some 1,500 ft. into the granite of Ben Nevis, whilst this was still liquid (*see ante*, p. 55).

Mode of Eruption of the Lavas.—In Western Scotland both the Lower Old Red and the Tertiary volcanic provinces have dyke-swarms genetically connected with cauldron-subsidences. At the Etive Old Red centre and at the Mull Tertiary centre the dyke-swarms cut the associated lava-plateaux. No instance of a dyke feeding a lava-flow has been observed. The lavas in both provinces are therefore regarded by the Geological Survey as the products of central volcanoes (*cf.* Fig. 14), not of fissure eruptions.[1] In both provinces sites of the smaller volcanic vents are inconspicuous. In the case of the Lower Old Red volcanic rocks there is confirmatory evidence of central eruptions. Very similar suites of lavas and tuffs are widely distributed in the Midland Valley of Scotland, but they are not there cut by dyke-swarms, and a number of scattered vents have been located.

[1] *See* J. E. Richey, 'Some Features of Tertiary Volcanicity in Scotland and Ireland,' *Bull. Volcanol.*, Sér. ii, tome i, 1937, p. 15, for other evidence.

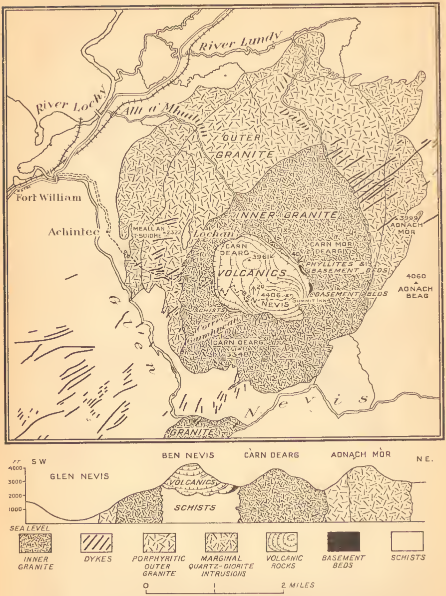

Fig. 18.—*Geological Map and Section of Ben Nevis, partly after J. G. C. Anderson*, 1935.

In Western Scotland, as in the Midland Valley, the penetration of fine-grained sediment into cracks and cavities in the flows, and the intercalation of conglomerates, are characteristic features of the lavas. Pillow-structure is, however, unknown and the flows are not regarded as having consolidated under water. The lavas buried a hilly schist topography and are believed to have been erupted in a semi-arid terrain subject to periodic torrential floods.

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2. MIDDLE OLD RED SANDSTONE

Along the south shore of the Moray Firth, between Inverness and Nairn, and around Fochabers, there occur extensive areas of rocks referred to the middle division of the Old Red Sandstone. Inland several large outliers (Fig. 19), mostly preserved through faulting, are found—the chief are those

Fig. 19.—*The Old Red Sandstone and Permo-Trias north of the Grampians.*

of Drynachon Lodge, Tomintoul, Cabrach, Rhynie and the large Gamrie–Turriff outlier. The Middle Old Red Sandstone rests with violent unconformity upon the Highland Schists; around Elgin and Nairn it is covered unconformably by the Upper Division of the formation. The general succession of the Middle Old Red Sandstone begins with a basal conglomerate which is followed by shales with fish-bearing beds, and these by sandstones and flags, but correlation bed by bed between the various outliers is as yet impossible.

The Inverness–Nairn outlier shows the following succession:—

1. Basal Conglomerate.
2. Fish-bands of Nairnside and Clava, and associated flagstones. From these have been obtained: *Dipterus valenciennesi*, *Coccosteus decipiens* and *Osteolepis* at Easter Aultlugie and *C. decipiens*, *Mesacanthus* and *Cheirolepis* at Clava Bridge, and *Cheiracanthus murchisoni*, *Cheirolepis traillі*, *Coccosteus* cf. *decipiens*, *Diplacanthus striatus* at Knockloam.

3. Leanach and Dores Sandstones with *Pterichthys milleri*, *Coccosteus decipiens*, *Homosteus* and *Glyptolepis*.
4. Inshes and Holm Burn Flagstone Group—sandy flagstones, dark calcareous flags and shales, micaceous sandstones and shales, with *Coccosteus decipiens*, *Osteolepis* and plant-remains.
5. Hillhead Sandstones, flagstones and shales with *Coccosteus minor* and *Homosteus milleri*.

The south-eastern portion of the Nairn outlier is celebrated for the classic fish-localities of Lethen, Lethen Bar and Clune, about six miles south-east of Nairn. The rapidly varying basal conglomerate is followed by thin sandstones, shales, calcareous nodules and thin seams of limestone, the latter making the fish-band at one time worked for lime. From these localities the following fishes were obtained: *Diplacanthus striatus*, *Rhadinacanthus longispinus*, *Mesacanthus pusillus*, *Cheiracanthus murchisoni*, *C. latus*, *Pterichthys milleri*, *P. productus*, *P. oblongus*, *Dipterus valenciennesi*, *Glyptolepis leptopterus*, *Gyroptychius microlepidotus*, *Osteolepis macrolepidotus*, *Diplopterus agassizi*, *Coccosteus decipiens*, *Cheirolepis trailli*. This fauna bears remarkable similarity to that of the Achanarras beds of the Caithness Flags of Caithness. The Hillhead Group of the preceding table is the highest horizon of the Middle Old Red Sandstone recognized on the south side of the Moray Firth, and corresponds to the Thurso Group of the Caithness succession.

East of Elgin around Fochabers on the Spey, a considerable development of beds similar to those of Nairn is found resting unconformably on the Highland Schists and covered unconformably by Upper Old Red Sandstone. Basal conglomerates are followed by shales and red sandstones with the Tynet Burn Fish-bed. This bed contains a fauna similar to that given above from the Lethen and Clune district. Still farther east is the great outlier of Gamrie–Turriff, faulted down on its western side into the Highland Schists. It consists of two divisions: (1) the Lower or Crovie Group of conglomerate followed by sandstones, flags and marls with ribs of limestone, and bright red sandstone; and (2) Upper or Findon Group, consisting of coarse conglomerates with a seam of red clay containing ichthyolites which have yielded the Achanarras fauna similar to that listed above.

In the valley of the River Bogie, south of Huntly, the Rhynie outlier is found limited on its western side by a large fault. This outlier is celebrated on account of the beautifully preserved plant-remains in a silicified peat discovered by W. Mackie and described by R. Kidston and W. H. Lang. The succession from below upwards is (1) basal breccia and conglomerate, (2) lower red shales with calcareous band, (3) Tillybrachty sandstones with volcanic zone, (4) Quarry Hill Sandstone, and (5) Dryden Flags with which the plant-bearing Rhynie Chert is interbedded. The plants belong to a group Psilophytales, allied to the Pteridosperms. The chief genera are *Rhynia*, *Hornia* and *Asteroxylon*.

Volcanic rocks are developed on a small scale in three of the Moray Firth outliers of Middle Old Red Sandstone. A flow of vesicular andesite occurs in the Rhynie outlier, and another of similar nature in the adjacent Cabrach outlier. The former is associated in the field with an olivine-dolerite possibly of intrusive origin. A hornblende-andesite lava is found in the Gollochy Burn near Buckie in the Fochabers outlier. An andesite sill cuts the Highland Schists three and a half miles west-south-west of Cullen in Banffshire.

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3. UPPER OLD RED SANDSTONE

In a belt stretching from Nairn by Forres to Elgin and beyond, beds referable to the upper division of the Old Red Sandstone rest unconformably on various members of the Middle Old Red Sandstone or upon the Highland Schists (Fig. 19). In the Upper Old Red Sandstone of this district three life-zones were established by R. H. Traquair. These are:—

1. Lowest or Nairn Sandstones with *Asterolepis maxima*.
2. Alves and Scaat Craig Beds with *Bothriolepis major* and *Psammosteus taylori*.
3. Rosebrae Beds with a fauna bearing a striking resemblance to that found in the Dura Den sandstones in Fife.

In the Findhorn area the Nairn Beds consist of a basal breccia, followed by coarse false-bedded sandstones with layers and galls of clay, and occasional irregular beds of conglomerate which pass below grey flaggy sandstones. These are overlain by the Cothall Limestone, a concretionary limestone 10 ft. thick, which is in turn succeeded by calcareous sandstones and marls. The following fishes were obtained by W. Taylor from the sandstone in the Findhorn section: *Psammosteus taylori, Cosmacanthus, Asterolepis maxima, Bothriolepis major, Holoptychius nobilissimus.* This list is of interest in that it shows a mingling of forms characteristic of the Nairn and Alves beds.

In the Muckle Burn area, west of the Findhorn, the basal member of the Upper Old Red Sandstone is a breccia 15 ft. thick. This is succeeded by sandstones, with occasional conglomeratic flaggy and clayey bands. At Glenshiel these sandstones yielded *Asterolepis maxima*, whilst from two localities, Boghole and Whitemire, W. Taylor obtained the following assemblages:—

Whitemire: *Psammosteus taylori, Cosmacanthus, Asterolepis maxima, Bothriolepis major, Conchodus, Holoptychius nobilissimus.*
Boghole: *P. taylori, Asterolepis alta, H. nobilissimus, H. decoratus, Polyplocodus, Coccosteus magnus.*

The same commingling of Nairn and Alves forms is noted as that found in the Findhorn faunas.

In the Nairn area the Nairn beds proper consist of grey and yellow false-bedded sandstones with seams of clay and occasional flags and shales. From these beds were obtained *Psammosteus tesselatus, Asterolepis maxima, Holoptychius decoratus, Polyplocodus leptognathus, Coccosteus magnus.*

The Alves and Scaat Craig sandstones occur in the Elgin district and have yielded *Bothriolepis major, Psammosteus pustulatus, Polyplocodus, Cosmacanthus malcolmsoni, Conchodus ostraeiformis, Holoptychius giganteus, H. nobilissimus* and *H. decoratus.*

In Quarry Wood, near Elgin, the Scaat Craig Beds are succeeded by a fine-grained sandstone, the Rosebrae Beds, which contains *Bothriolepis major, B. cristata, Phyllolepis concentrica, Phaneropleura andersoni* and *Glyptopomus minor.* The last three species are characteristic of the main fish-bed of Dura Den in Fife.

W. Mackie has studied in detail the heavy residues of the sandstones of the Elgin and adjacent districts. These minerals are large and angular in the rocks of the Middle Old Red Sandstone but small and rounded in the Upper Division, an expression of the different conditions of deposition of the two series, the first as torrential or lacustrine deposits, the second as continental wind-blown deposits. Different assemblages of heavy minerals characterize the two divisions: the Middle Old Red Sandstone shows dominant garnet, with abundant iron-ore, rutile, monazite, staurolite, etc., but rare zircon and tourmaline, whereas the Upper Division has zircon as its main heavy mineral, with abundant tourmaline, rutile, anatase, monazite, etc., but rare or absent garnet.

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X. CARBONIFEROUS

NORTH OF THE Highland Boundary Fault, rocks of Carboniferous age occur at four widely separated localities in Argyllshire. The most northerly is at Inninmore Bay on the north shore of the Sound of Mull, where there is a small outlier of Upper Carboniferous sediments overlain by Triassic and Lower Liassic strata and underlain, probably directly, by Moinian. This locality, being north of the Great Glen, is referred to in 'British Regional Geology: The Northern Highlands.' The other three Carboniferous outcrops lie within the Grampian Highlands area; they occur: (1) at Bridge of Awe, towards the west end of the Pass of Brander, (2) on Glas Eilean, in the Sound of Islay, and (3) at Machrihanish in the Kintyre Peninsula. The largest of these outliers, which covers about twelve square miles between Machrihanish and Campbeltown, contains worked coals of the Limestone Coal Group.

Bridge of Awe.—A few exposures on the banks of the River Awe, mainly above Bridge of Awe, indicate the occurrence of a small outlier of Carboniferous sediments, about one-fifth of a square mile in area, resting on Lower Old Red Sandstone lavas. The beds consist of 50 ft. to 60 ft. of gritty sandstones, mottled marls, and purplish shales, together with some lighter coloured shaly sandstones which have yielded a few poorly preserved plant remains. The Carboniferous age of the sediments is shown by the presence of plant species probably to be referred to the genus *Asterocalamites*, and of forms very like *Rhacopteris petiolata* (Goepp). In 1899, Kidston expressed the opinion that the plants had 'a Calciferous Sandstone (Lower Carboniferous) facies,' but the recent review of available evidence (1940) leaves their position in the Carboniferous succession still uncertain. Lithologically the Bridge of Awe beds have a resemblance to certain of the lower strata at Inninmore, twenty miles west-north-westwards on the Sound of Mull. W. Q. Kennedy has used the occurrence of Carboniferous rocks at these two localities as an argument in favour of assigning a Pre-Upper Carboniferous age to the main movement along the Great Glen Fault (1946).

Glas Eilean.—On this islet, on the east side of the Sound of Islay and three miles S.S.E. of Portaskaig, 20 ft. or so of conglomerate, made up almost entirely of rounded or sub-angular pebbles of Jura Quartzite, are succeeded by a few feet of reddish-brown, fine-grained sandstone, followed by some 200 ft. of volcanic rocks. These lavas comprise four flows of olivine-basalt, in which analcite has locally been recognized. Thin layers of sandstone are present on the slaggy tops of the two lowest flows; a 6-in. fine-grained, sandy limestone, overlying the third flow, is regarded as a product of hot springs. Since no associated fossils have been found, the age of the rocks depends mainly on petrological evidence afforded by the lavas. These were originally assigned, without detailed microscopic examination, to the Lower Old Red Sandstone (Geikie, 1899). A recent investigation by Pringle, A. G. MacGregor and Bailey, has led to the conclusion that they are Carboniferous; they may belong either to a Calciferous Sandstone or to a Millstone Grit Volcanic episode (Pringle, 1944).

Machrihanish.—The subdivisions of the Carboniferous of Machrihanish and Campbeltown range from Calciferous Sandstone Series to Coal Measures (Fig. 20). The former consists of a thick development of volcanic rocks (olivine-basalts, trachyandesites, and trachytes: *see* McCallien, 1928), overlain by some reddish clays of a bauxitic nature, formed as residual and detrital lateritic deposits derived from contemporaneously decomposing lavas (cf. MacGregor, 1937, pp. 50–51). There are associated intrusions, mainly trachytic (orthophyre and keratophyre: *see* McCallien, 1928). The Carboniferous Limestone Series rests unconformably on the volcanic rocks. On the shore at Machrihanish red limestone and limy shales assigned to the Lower Limestone Group succeed the red bauxitic clays above the lavas.

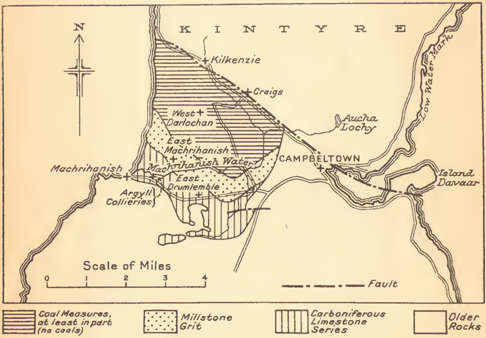

FIG. 20.—*Geological Map of the Machrihanish Coalfield.*
(Reproduced from Fig. 15 in ' Report of the Scottish Coalfields Committee,' *Scottish Home Dept.*, 1944.)

There is some evidence to suggest that the succeeding Limestone Coal Group rests, with an easterly overlap, on an irregularly eroded floor of Calciferous Sandstone volcanics and that, accordingly, the full succession is only present in the west. Nothing is known about the development of the Group in the deeper northern part of the Machrihanish field, but in this direction the Main Coal, where not cut out by overlap, must lie at progressively greater depths. The Group is about 450 ft. in thickness and contains a number of coal seams, one of which, the Main Coal, has been extensively wrought; old workings extend for some distance under the sea. The Main Coal, generally 10 ft. to 12 ft. thick, but of inferior quality near the top, was worked from the old Argyll Colliery; the workings were discontinued in 1925 owing to an outbreak of fire. Mines are, however, now being driven to open out the coal in an untouched area. A thick sandstone forming the roof of this seam was also mined underground, principally as a source of moulding sand. A coal, about 110 ft. above the Main, was at one time worked on a small scale; this Kilkivan Coal was last wrought for a short time between 1925 and 1927. The Limestone Coal Group is succeeded by the Upper Limestone Group, locally about 270 ft. thick and containing three or four marine limestones. The sequence above this Group is known only from a few borings which are difficult to interpret. First there is Millstone Grit, composed of interbedded volcanic and sedimentary rocks, and including beds that may possibly be of a bauxitic nature. Above comes a series of sandstones, shales, and clays, with some thin coals, assigned on the evidence of a few plant remains (*Neuropteris*, etc.) to the Productive Coal Measures. Above the Coal Measures there is a considerable thickness of red sandstone and marl, the age of which has yet to be proved.

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Islay and Kintyre.—At Port nan Gallan, a mile east of the Mull of Oa at the south end of Islay, a breccia associated with a sea-stack of limestone and schist has been described by B. N. Peach as filling a swallow-hole, or underground cavern, in the Islay Limestone. The breccia consists of blocks of quartzite, limestone and schist set in a matrix of bright red sandstone composed of well rounded grains of quartz; according to Peach (1907) it resembles the basement beds of the 'Trias' of Arran, Ballantrae and Loch Ryan. These basement beds in the Firth of Clyde area have subsequently been assigned to the Permian.

Twenty-five miles to the east, on the west coast of Kintyre, there are bright red false-bedded sandstones with intercalated bands of coarse breccia composed of vein-quartz, mica-schist, and quartzite. The sandstones have wind-rounded and polished quartz grains and contain facetted pebbles of dreikanter type. The outcrops fringe the coast for at least eight miles, between Bellochantuy and Glenbarr, and northwards of Glenacardoch Point to Killean. These beds have long been allocated to the Upper Old Red Sandstone; but J. Pringle in a paper read to the Edinburgh Geological Society in 1947, has pointed out the above evidence of their desert origin and has claimed that the Islay and Kintyre occurrences are both of Permian age. This claim seems well founded, for specimens of the Kintyre sandstones are indistinguishable from the Permian desert sandstone of Mauchline in Ayrshire.

Moray Firth.—North of Elgin there are extensive sandstone outcrops so separated by expanses of drift, etc., that it is impossible to tell their stratigraphical relationships. It is probable that these outcrops are considerably faulted. These beds contain remarkable reptilian faunas, the affinities of which show them to be of Permian or Triassic ages.

The sandstones under description (Fig. 19) have been considered by D. M. S. Watson in three areas: (1) Cuttie's Hillock, (2) Cummingstone, (3) Lossiemouth. The *Cuttie's Hillock sandstones* are coarse, with wind-rounded grains and abundant dreikanter, testifying to the desert conditions under which they were laid down. They rest with an irregular surface on the Rosebrae Beds of the Upper Old Red Sandstone (*see ante*, p. 64). They contain a remarkable reptilian fauna, *Gordonia*, *Geikia*, *Elginia*, compared by D. M. S. Watson to that of beds slightly higher than the Upper Permian Pariasaurian Beds of Russia, or of the Cisticephalus Zone of South Africa. These horizons represent the extreme top of the Permian or the boundary between Permian and Triassic. The *Cummingstone Beds* have so far yielded only footprints, but they are probably the equivalent of the Cuttie's Hillock Beds. The *Lossiemouth Beds* are also terrestrial deposits, and consist of soft, nearly white, fine-grained sandstone (Pl. VIIB). They have yielded *Dasygnathus longidens* Hux., *Telerpeton elginense* Mantell, *Hyperodapedon gordoni* Hux., *Stenometopon taylori* Boulenger, *Stagonolepis robertsoni* Ag., *Erpetosuchus granti* E. T. Newton, *Ornithosuchus woodwardi* E. T. Newton, *Scleromochlus taylori* A. S. Woodward, *Brachyrhinodon taylori* von Huene, *Saltopus elginensis* von Huene. This fauna is considered to be Middle Triassic, probably equivalent, according to von Huene, to the Lettenkohle of Germany. Watson estimates that the thickness of the sandstones in the three areas are: Cuttie's Hillock, 120 ft; Cummingstone, 400–500 ft.; Lossiemouth, 200 ft.

The heavy residues of the Elgin sandstones have been studied by W. Mackie, who finds that the Gordonia beds of Cuttie's Hillock have an assemblage quite different from those yielded by the Old Red Sandstone and the Trias. The constituent grains of the Gordonia beds are exceedingly well rounded and polished; of the heavy minerals, zircon is abundant, tourmaline is less common than in the underlying Rosebrae Beds, monazite, hornblende, topaz and anatase are always present, whilst augite, enstatite and corundum are frequently found. Fluor and barytes are always present in small amount. In the Triassic rocks the grains are subangular, whilst garnet is plentiful and usually angular. Zircon, tourmaline, monazite, hornblende are common. Fluor and barytes are present, often in large amount, fluor varying from 30 per cent of the total rock down to a few grains. These two minerals form the cement of certain sandstones of the coastal Trias.

At Lossiemouth the Trias is possibly followed by the 'Cherty Rock of Stotfield,' considered by some to be of Jurassic age. D. M. S. Watson has compared this rock to the superficial chalcedony which develops in certain dry sandy regions such as the Fayum.

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XII. LATE-CARBONIFEROUS AND POST-CARBONIFEROUS MINOR INTRUSIONS

1. Permo-Carboniferous Quartz-Dolerite Dykes

In the south-west Highlands there are innumerable examples of east-and-west-trending quartz-dolerite dykes which cut the north-north-east suite of Lower Old Red Sandstone age and are themselves cut by the north-west Tertiary suite described later. These quartz-dolerite dykes are comparable with the quartz-dolerite dykes of Permo-Carboniferous age in the Midland Valley, of which some of the Highland dykes are clearly continuations. Good examples of these dykes are seen in Cowal—at Carrick, Lochgoilhead, Loch Restil, etc. The Lochgoilhead dyke is probably the continuation of the set that begins at Perth, seventy miles away. Less abundant representatives of the quartz-dolerite suite are found farther north in the Perthshire Highlands, Deeside and Buchan. In Buchan a dyke, forty miles long, extends from Peterhead westwards to Rothie Norman (Sheet 86). The quartz-dolerites consist of basic plagioclase, ophitic augite, iron oxide and micropegmatitic mesostasis.

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2. Camptonite Suite of South-west Highlands

At various localities in the South-west Highlands—Colonsay, Scarba and Loch Leven—there are found camptonite and monchiquite dykes whose age is a subject of discussion. These dykes run in agreement with the north-west dykes of Tertiary age. They are later than the minor intrusions of Lower Old Red Sandstone age and than the Permo-Carboniferous quartz-dolerite dykes. They are cut by definitely Tertiary dykes, but have never been seen to cut Mesozoic sediments or Tertiary lavas. A. Harker grouped with these dykes others composed of crinanite and olivine-dolerite and considered the whole assemblage to be of Permian age. That the camptonite suite is late Carboniferous or Permian seems very probable as a result of W. D. Urry's determination of the ages of two monchiquite dykes in Colonsay, by the helium method.

A small patch of breccia, with an intrusion of nepheline-basalt, occupies

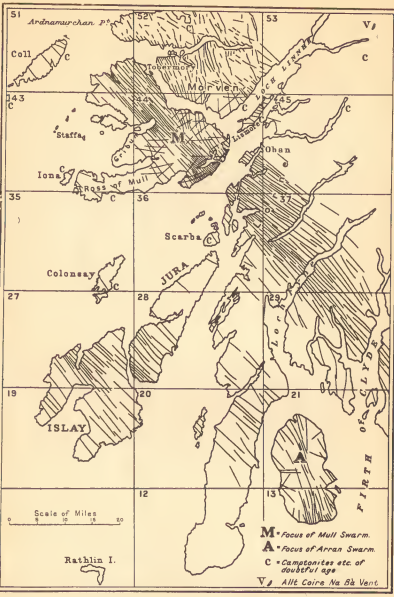

FIG. 21.—*Distribution of Tertiary (and Permian or Tertiary) Dykes in the South-west Highlands, and its Relation to the Tertiary Centres.*

an explosion vent in Coire na Bà (Sheet 53); this may be of Permian age.

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3. Tertiary Dykes, etc.

In the South-west Highlands an immense number of dykes, mostly basic, run north-west or north-north-west (Pl. VIIIa). These dykes are connected with the Mull and Arran centres of Tertiary igneous activity (Fig. 21). They consist of basalts, mugearites, crinanites, trachytes, teschenites, tholeiites, andesitic pitchstones and andesitic, trachytic and rhyolitic types. Dykes of the Mull Swarm traverse Lorne and reach the Firth of Clyde; the Arran Swarm is represented by dykes of Islay, Jura and Kintyre. Composite and multiple examples are abundant.

F. Walker has recently described an elongated boss on Maiden Island, Oban, which provides the only recorded occurrence, in the British Tertiary province, of the development of picrite marginal to olivine-dolerite.

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XIII. PLIOCENE(?), PLEISTOCENE AND RECENT

1. Pliocene (?)

IN THE BUCHAN district of Aberdeenshire several small patches of gravels, composed mainly of quartzite pebbles, occur at an elevation of 350 to 400 ft. above O.D. These gravels contain flints with Cretaceous fossils and are overlain by the lowest boulder-clay of the district. It has been suggested by Sir J. S. Flett and H. H. Read that these gravels are possibly of Pliocene age and indicate a submergence of this part of Scotland of at least 400 ft.

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2. Pre-Glacial Raised Beach of the West of Scotland

Throughout a small area in the west of Scotland there is a well-developed pre-Glacial shore-line at 100 to 135 ft. above high-water-mark (Pl. VIIIb). It occurs in Colonsay, Oronsay, Mull, Islay and Iona. Its inner margin is marked by a line of cliffs. It has been studied by W. B. Wright, who tentatively correlates it with the pre-Glacial shore-line of South Britain.

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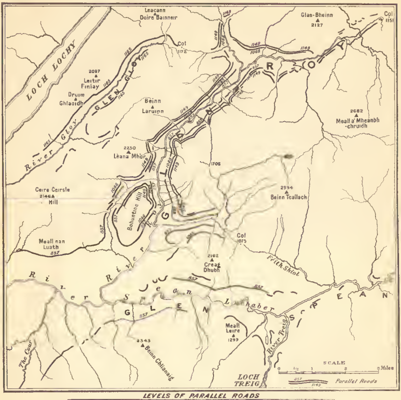
3. Glacial Period

The Grampians were the great centre of ice-dispersal in the Glacial period in the Central Highlands. Glaciers crept out from them on all sides and coalesced into an ice-sheet that overflowed Scotland from shore to shore. During the epoch of maximum glaciation the general movement in the South-western Highlands was to the south-west, being controlled by the major features such as Loch Linnhe and the Sound of Mull, Glen Orchy and the Loch Awe hollow. As the ice coalesced in Lorne and Knapdale the main direction of movement became more westerly, the ice passing across Colonsay and Jura from east to west and across Islay from south-east to north-west. Similarly, the Cowal watershed divided the ice from the north-east into two streams, one down Loch Fyne, the other down the Firth of Clyde. Farther north-east in the Central Highlands the main movement from the Grampians was to the east and south-east. The Moor



LEVELS OF PARALLEL ROADS

	GLEN GLOY					GLEN ROY				GLEN SPEAN			
	Highest	Lowest	Average	Col		Highest	Lowest	Average	Col	Highest	Lowest	Average	Col
1	1173	1156	1165	1172	1	1155	1144	1148	1151				
					2	1077	1062	1067	1075				
					3	862	850	855	848	862	850	855	848

FIG. 22.—*Map of the Parallel Roads of Glen Roy.*

The Parallel Roads are terraces marking the successive levels of glacier-dammed lakes, their heights corresponding with three cols which in turn controlled the lake-levels.

of Rannoch formed a great ice-reservoir with radial dispersal. On the north side of the Cairngorms the general flow was north and north-east, but this was interfered with by ice from the west coming from the Northern Highlands. The later stage of valley-glaciers was controlled more by the form of the ground, the ice being confined to the main valleys. Finally the ice shrank into the high corries.

Boulder-clay, the deposit of the main glaciation, forms featureless spreads over the lower grounds. Sandy, gravelly and clayey beds are often intercalated in this deposit. Certain of these beds found in the boulder-clay have given rise to considerable discussion. The most important of these is the *Clava Shell Bed* in Nairnshire; this consists of fine marine silt occurring at a height of 500 ft., and covered by 45 ft. of boulder-clay. It has been interpreted as a transported block or as due to

Fig. 23.—The Three Stages in the Glaciation of North-east Scotland, after A. Bremner.

(*C.*2340)

A.—Glen Roy, 'Parallel Roads'

(*C.*1383)

B.—Mam Suim, Strath Nethy
[For explanation, *see* p. viii]

(*C*.287)

A.—Cliff, River Spey, opposite Rothes
[For explanation, *see* p. viii]

(*C*.1491)

B.—West of Cullen, Banffshire
[For explanation, *see* p. viii]

(*C.*2370)

A.—Looking down River Roy, Glen Roy. Successive river terraces

(*B.*793)

B.—Culbin Sandhills, Moray. Blown-sand Topography

submergence. During the retreat of the valley-glaciers deposits often of good morainic form were laid down in the valleys. To this stage belong the retreat phenomena characterized by overflow channels (Pl. IXB), marginal deposits and especially by glacial lakes, such as those indicated by the old shore-lines of the Parallel Roads of Glen Roy (Fig. 22 and Pl. IXA), Loch Tulla, etc. Such lakes formed in valleys blocked by ice-dams across their mouths. Extensive spreads of gravel and sand were caused by outwash from the retreating glaciers (Pl. XA).

In North-east Scotland, as shown by T. F. Jamieson, A. Bremner, H. H. Read and others, the glaciation is more complicated. In Lower Banffshire the earliest ice-movement came from the north-west, and carried shells from the Moray Firth, great erratics of Jurassic clays and fragments of Cretaceous rocks. This was followed by the deposition of a series of clays, sands and gravels (Coastal Deposits of Read) which are covered by the boulder-clay produced by a movement from the south. Outwash gravels provide the next stage of the glacial deposits, and, finally, there was a further glaciation from west and north-west. The early south-easterly movement continues to Aberdeen. Farther south the sequence obtained by A. Bremner is (1) Lower Grey Boulder Clay of the maximum glaciation, (2) Strathmore drift—sands, gravels, clays and boulder-clays deposited by ice moving north-north-east along the coast—and (3) Upper Grey Boulder Clay, moraines and gravels. The cause of the deflection of the Strathmore ice and of the early south-easterly ice of Banffshire was the presence of the Scandinavian Ice-sheet in the North Sea (Fig. 23). Erratics of Norwegian rocks have been found at Portsoy, Ellon, Bay of Nigg and elsewhere. It may be suggested that a boulder-clay—the Indigo Boulder Clay of T. F. Jamieson—formerly seen below the Lower Grey Boulder Clay of the Ellon district in Buchan may be Scandinavian drift.

4. Raised Beaches

100-ft. (*Late Glacial*) *Beach.*—While the Highlands were still covered with ice and great glaciers filled the main valleys there took place a submergence of about 100 ft., giving a well-marked raised beach, the *100-ft. Beach.* With the deposits of this age are found clays with an arctic fauna. The shore lines of this sea are well developed in the Western Islands, where great shingle beaches have been formed. The 100-ft. Beach was excluded from the upper parts of some of the firths, such as Loch Linnhe, by the ice of the Glacial period.

50-ft. Beach.—What is possibly a group of beaches at heights of between 65 ft. and 45 ft. is fairly well marked. This stage may represent a pause in the retreat of the sea. This retreat continued till the sea-level was much lower than the present, as evidenced by the *Submerged Forests.* Remains of forests, peats and old land surfaces are now found below high-water-mark.

25-ft. (*Neolithic*) *Beach* (Pl. XB).—As shown by T. F. Jamieson, the Submerged Forest period was followed by submergence which ended at the 25-ft. beach. This beach varies in height from 0 to 35 ft. above the present shore; the height is a maximum at Loch Linnhe and decreases gradually away from this locality. The deposits of this period contain a present-day fauna. At Balnahard, at the north end of Colonsay, the sandhills contain a Neolithic floor at a height of 22 to 23 ft. which may possibly have been formed at the time of the 25-ft. beach. The 25-ft. beach is well developed at Oban, where old sea-stacks and sea-caves occur; in the caves here traces of Azilian culture have been found.

5. Recent Deposits

Freshwater Alluvium.—Most of the streams of the Grampian Highlands are bordered by one or more terraces marking the successive levels of their flood-plains (Pl. XIa). The larger rivers, such as the Spey, Tay, Deveron, etc., flow for most of their courses through wide alluvial plains. The higher and older of these terraces are in many cases of fluvioglacial origin, being laid down on the melting of the ice of the Glacial period. Deltaic deposits, except at the heads of some of the lochs, are not developed on an extensive scale.

Peat.—Much of the higher ground is covered by a mantle of peat, often 20 ft. or more in thickness, which is in many cases being subjected to denudation and wasting. In the Grampians, the lowest layer of peat contains Northern plants—the second Arctic bed of F. J. Lewis—and is followed by the main thickness of peat in which are two layers with pine-stumps which together form the Upper Forestian of Lewis. Elsewhere in Scotland, a lower forest, with birch remains, is found below the Arctic Bed.

Blown Sand.—Where a suitable supply of raw materials was available and the nature of the sea currents and the type of climate were favourable, there have been formed deposits of blown sand. The most important of these occur on both sides of the mouth of the River Findhorn, giving the Maviston and Culbin Sandhills (Pl. XIb). The Culbin Sandhills cover an area of about six square miles and rise to a height of a hundred feet. There are dunes 10 to 30 ft. high, showing conical, crescentic or ridge forms. The encroachment of the sand culminated in the great storm of the autumn of 1694, when a mansion house, sixteen farms and crofter cottages, with a rental which at the present day might have yielded £6,000, were overwhelmed. There is in this region a combination of conditions favourable for the formation of large blown-sand deposits. The Findhorn transports great quantities of sand to the sea and this material is swept on to the shelving beaches by current and tidal action. It is then caught up by the prevalent westerly winds and carried inland. In the adjacent Maviston sandhills, it is recorded that the sandhills have travelled eastwards nearly a mile during the present generation.

Other large areas of blown sand are found on the Aberdeenshire coast between Fraserburgh and Peterhead, at the mouth of the River Ythan and farther south to Aberdeen. In Islay, blown sand makes an extensive spread on Big Strand, Laggan Bay.

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XIV. ECONOMIC GEOLOGY

Water Supply and Hydro-Electric Power.—Water is obtained from superficial deposits and sandstones, by impounding, and from springs. Lochs and rivers are used as sources to supply, for example, Glasgow (Loch Katrine), Aberdeen (River Dee). (*Mem. Geol. Surv., Min. Resources*, vol. xxxiii.)

Hydro-Electric power is used for the manufacture of aluminium at Fort William, Kinlochleven, and Foyers, and a scheme in the Central Grampians supplies electricity for general consumption to a wide area. Extensive developments are planned by the North of Scotland Hydro-Electric Board whose projects at Loch Sloy and Pitlochry are already well under construction. (Fulton, 1945.)

Peat.—Peat is dug for fuel in many parts of the area, and has specialized uses in the distilling of whisky, and in fish curing. (*Geol. Surv. Wartime Pamphlet*, no. 36.)

Road Metal.—Road metal is obtained from quarries in the less schistose varieties of metamorphic rock: granulites, quartzites, grits, epidiorites, limestones, etc., or in the igneous rocks : Newer Granites, Lower Old Red Sandstone intrusions, or dykes of Permo-Carboniferous or of Tertiary age. The porphyry sills on Loch Fyne are worked at Furnace and Crarae to provide setts for Glasgow. (Phemister and others, 1946.)

Sand, Gravel, Brick-Clay.—These materials are obtained from superficial deposits. (Anderson, 1943 ; *Geol. Surv. Wartime Pamphlets*, nos. 30, 47.)

Diatomite.—Several small occurrences of diatomaceous earth are known in the Central Highlands, but a more important deposit of this type occurs at Moor of Dinnet, Deeside, where the material was at one time extensively worked. (*Geol. Surv. Wartime Pamphlet*, no. 5.)

Building Stone.—Sandstones are employed for rough work. Freestones of good quality are obtained from the Permo-Trias of Elgin, and of rather less good quality from the Lower and Middle Old Red Sandstones. Many of the groups of the Highland Schists provide material, often either of a slabby or flaggy type or else rather intractable. The granite industry is mainly centred on Aberdeen, where the local Caledonian granites are employed; a considerable stone-polishing industry uses, in addition, imported material. Granites (including more basic types) have been quarried in the South-west Highlands near Ballachulish, and are still worked on Loch Etive. (*Mem. Geol. Surv., Min. Resources*, vol. xxxii.)

Slates.—Extensive slate working is, or has been, carried on in the Ballachulish district, and in Easdale and the adjacent islands. Slates have also been quarried at many localities along the Highland Border, and are still worked at Aberfoyle and Luss. The Macduff Slates of Banffshire were formerly quarried on a considerable scale, but the slates produced were rather thick. (*Geol. Surv. Wartime Pamphlet*, no. 40.)

Limestone.—Limestones of the Dalradian Series are quarried and ground for agricultural purposes in several parts of the Grampian Highlands, particularly in the counties of Banff, Perth, and Argyll. Only a small proportion of the stone is now burned, although formerly there were working kilns in almost every district in which limestone occurs. (*Geol. Surv. Wartime Pamphlet*, no. 13; *Mem. Geol. Surv., Min. Resources*, vol. xxxv.)

Dolomite.—In the Duror District of Argyllshire there is a thick dolomitic band of Appin Limestone which has been analysed; it is described as a fairly good commercial dolomite, possibly suitable for use as a basic refractory, or for the extraction of metallic magnesium. (*Geol. Surv. Wartime Pamphlet*, no. 6.)

Coal and Bauxitic Clay.—The occurrence of these Carboniferous deposits at Machrihanish in Argyllshire is referred to in Chapter X.

Graphite.—Thin veins of graphite and belts of low-grade graphite-schist are found in many parts of the Central Highlands, but in no case in sufficient quantity to be worth working. In Lower Banffshire and Strathbogie belts of graphite-schist are common in the Portsoy Group of the Highland Schists, whilst in the same area veins of graphite have been recorded near Huntly, in the Cabrach and elsewhere.

Talc (soapstone).—Talc, resulting from the shearing of serpentine, is quarried near Portsoy, Banffshire, and was formerly mined at Inellan in Cowal. Talcose soapstone occurs in the Corrycharmaig (Perthshire) serpentine. (*Geol. Surv. Wartime Pamphlet*, no. 9.)

Chromite and Magnesite.—Chrome iron ore, disseminated through antigorite-serpentine, was once worked on the farm of Corrycharmaig, four miles north-west of Killin. This small mass of serpentine includes local areas in which magnesium carbonate (magnesite or breunnerite) occurs in considerable quantities. It has been suggested that natural associations of chromite, antigorite and magnesite may prove of value as a source of raw materials for the manufacture of chrome-magnesia refractory bricks. (*Geol. Surv. Wartime Pamphlet*, no. 9.)

Feldspar.—A pegmatite vein near Portsoy in Banffshire is worked as a source of feldspar. Other pegmatites of possible value occur in the Central Grampians near Loch Laggan and Dalwhinnie. (*Geol. Surv. Wartime Pamphlet*, no. 44.)

Quartzite, Vein Quartz and Siliceous Sandstone.—The purer Highland quartzites would probably be serviceable for silica-brick making, although trials with material from Islay have not proved successful. The Appin quartzite near Kentallen was formerly quarried for use in grinding-tubs in the pottery industry. Quartz veins occur in many parts of the Grampian Highlands, but are generally thin and impersistent. A thick vein of great purity occurs near Dalwhinnie, but is rather inaccessible. A siliceous sandstone of considerable purity, belonging to the Limestone Coal Group, occurs in the Machrihanish Coalfield, and has been mined, mainly as a source of moulding sand. (*Geol. Surv. Wartime Pamphlet*, no. 7.)

Barytes.—Barytes is not common in the Central Highlands. It occurs sometimes in the crush-rock of late faults, and a lenticular vein has been recorded from Balfreish, in the Nairn valley, in the limestone at the base of the Middle Old Red Sandstone.

Manganese.—Manganese ores have been recorded from many parts of the Grampian Highlands. The three chief occurrences are those of the Lecht Mines, Tomintoul, of Oa, Islay, and of Dalroy, Nairn. The Lecht vein runs for a distance of three miles along a line of fault. The ore consists of brown hematite with a large quantity of psilomelane and a little wad. It was worked about the end of the eighteenth century. At the south end of the Oa peninsular, Islay, a network of manganite veins traversing quartzite was worked at one time. At Dalroy in the Nairn valley, a deposit of manganese ore of variable thickness fills hollows in the schist floor below the Old Red Sandstone.

Iron.—The ore of the Lecht Mine, Tomintoul, already mentioned in connexion with manganese, contains from 20 to 40 per cent iron. The ore is highly siliceous and fairly rich in phosphorus. At Arndilly, Craigellachie, Banffshire, veins of iron and manganese ores occur in breccia-lines in quartzite and have been worked. Associated with the pillow-lavas of the Highland Border Series at Stonehaven are lenticular beds of fine-grained siliceous ironstone and bands of black shale and jasper. The iron-content varies from 30 to 40 per cent. A hematite vein has been noted near Glen Ure House, Glen Creran, whilst small veins intersect the Moine granulites near Dalnaspidal, Perthshire (*Mem. Geol. Surv., Min. Resources*, vol. xi).

Lead and Zinc.—In Islay veins containing galena, blende, pyrites and chalcopyrite were worked up to 1862. They occur in the Islay Limestone and Esknish Slates. On both sides of Loch Fyne in Argyllshire, veins with galena and blende, together with copper ores, have been worked at many localities; the ore deposits are usually associated with the Ardrishaig Phyllites and adjacent quartzite and occur in two types, true veins and metasomatic replacements. Other old lead mines are situated in Glenorchy and Glen Creran. The most celebrated lead deposits of the Central Highlands are those of Tyndrum in Perthshire, where several parallel veins traverse the Highland Schists, and are closely associated with one of the great north-east fractures of the Highlands (*see* p. 3). The veins have a maximum thickness of 20 ft., and have a gangue of quartz, calcite and barytes; the primary ores are galena, zinc-blende, chalcopyrite and pyrites. Small trials have been opened on many thin lead-zinc veins in Perthshire. In Aberdeenshire argentiferous galena and zinc-blende in a vein of calcite and fluor were at one time worked at Abergairn, Deeside. A quartz-vein 12 ft. across, with galena and iron-pyrites has been noted in the Dulnan valley, Strathspey. Near Lossiemouth galena occurs disseminated through the Cherty Rock and the adjacent Triassic sandstones and was at one time worked. Many Scottish lead-zinc veins carry silver (2 to 10 oz. to the ton). Traces of gold are also found locally. A complex lead-zinc-copper ore, formerly worked at Stronchullin, near Ardrishaig, Argyllshire, showed the exceptional assay value of 4 oz. of gold to the ton; but the rich pocket soon became exhausted. (*Mem. Geol. Surv., Min. Resources*, vol. xvii).

Copper.—The occurrence of copper ores with lead and zinc ores in the Central Highlands has already been mentioned. In Islay at Kilsleven Mine copper ore was worked in the eighteenth century and intermittently since then. Around Loch Fyne several copper veins have been worked; near Kilmartin several veins up to 4 ft. thick cut an epidorite and consist of quartz and calcite carrying chalcopyrite. Another old mine near Inverary, originally opened for copper, provided between 1854 and 1867 a fair quantity of nickeliferous pyrrhotite; similar copper-nickel ore occurs at Craignure south-west of Inverary. On the east side of Loch Fyne around Kilfinan the Loch Tay Limestone and associated schists are in places impregnated with copper ores, malachite and sulphides, which have been worked. Other trials for copper ore have been made near Lochgilphead and Ardrishaig.

At Tomnadashan on the south side of Loch Tay the late Marquis of Breadalbane worked a deposit of chalcopyrite, etc., associated with a granitic rock and a lamprophyre in the Highland Schists. On A'Bhuidheanaich (Sheet 74) an aplite vein contains chrysocolla, malachite and chalcopyrite (*Mem. Geol. Surv., Min Resources*, vol. xvii).

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